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MECHANICAL ENGINEERING

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(Dr. Cecil H. Lander in Second Robert Thurston Lecture, 1926 Annual Meeting, A.S.M.E.)

OCTOBER 1927

THE MONTHLY JOURNAL PUBLISHED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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The Monthly Journal Published by

The American Society of Mechanical Engineers

Publication Office, 20th and Northampton Streets, Easton, Pa. Editorial and Advertising Departments at the Headquarters of the Society, 29 West Thirty-ninth Street, New York

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Price 60 Cents a Copy, $5.00 a year: to Members and Affiliates, 50 Cents a Copy, $4.00 a year. Postage to Canada, 75 Cents Additional; to Foreign Countries $1.50 Additional. Changes of address should be sent to the Society Headquarters.

Entered as second-class matter at the Post Office at Easton, Pa., under the Act of March 3, 1879.
Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on January 17, 1921.

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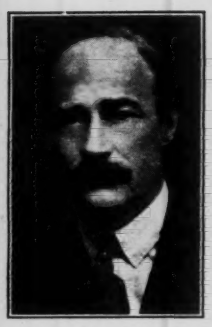

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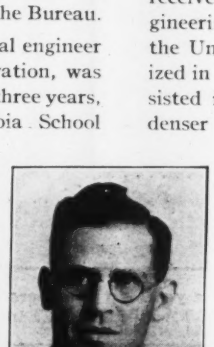

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MECHANICAL ENGINEERING

Volume 49 October, 1927 No. 10

The Economics of Coal Carbonization in the United States

By GEO. A. ORROK,[1] NEW YORK, N. Y.

ECONOMICS may be defined as the science of the useful application of the material resources of a country. Foster and Catchings have shown that to our pioneer ancestors this was a simple problem. The producer and consumer were one and the same individual or small group, and everything produced was consumed in the same community or saved for future use. The complications of our present-day civilization, however, have materially changed the problem. When the few thousands of people scattered in a thin line along the Atlantic coast were self-sufficient, the material resources of this country were not known and little realized, the soil yielded abundant returns, the waters and the forests added to abundance. Material resources were not in evidence, although rumors of gold deposits had much to do with the early settlements and our iron deposits were worked as early as 1635. The early settlers had brought with them a knowledge of coal and of its use as a fuel, and as the population increased both bituminous coal and stone coal, or anthracite, were used as a household fuel, while the forests furnished charcoal for such metallurgical processes as were demanded by the pioneer civilization. Bituminous coal had been used for fuel before the Revolution, while anthracite came into use for this purpose in 1808. Soon after, in 1812, the attempt was made to use anthracite coal in the iron industry. In that year, Shoemaker brought the first cargo of Lehigh coal in boats to Philadelphia, and had to give most of it away as it was charged he was attempting to sell stone for coal.

Early Carbonization Processes

The carbonization of bituminous coal was practiced in England early in the 16th century, when pit coal was burned in heaps similar to the charcoal kilns. The product of the carbonization, coke, was first used in England as fuel in the blast furnace about 1740, and had practically driven the charcoal furnace out of England in 1796. It was, however, in 1841 when McCormack and Campbell secured a coke contract in Pittsburgh and built the first two coke ovens in the Connellsville region. The use of coke did not spread quickly, and by 1855 only about 100 coke ovens were in operation in the United States.

The first successful use of carbonized coal in the blast furnace was at the Clinton furnace in Pittsburgh, in 1860, although many experiments had been tried in the twenty years preceding. Swank in his "The Manufacture of Iron in All Ages" chronicles the earlier experiments and final successes of the carbonization industry as he carries the story from 1585 to 1885—a period of three hundred years. Since that time the history and progress of the carbonization industry has been so intimately connected with the metallurgical industry, and in fact with the production of pig iron, that the curves of pig iron produced and coal carbonized are practically identical when the proper scales are used. (See Fig. 1.)

Adaptability of Coke to the Blast Furnace

I have said that the carbonization industry is intimately connected with the metallurgical industry, which is, perhaps, a weak statement in view of the actual facts. It is the use of coke, the main and most important product of the industry, which has made the modern blast furnace possible. Charcoal, weak in structure but free burning, could not carry burden. Anthracite could carry burden, but was slow, and a large output was never attained, while with coke as the fuel the size of the furnace has increased with the ability to take advantage of the strong structure and quick action of the product of the modern coke ovens.

Production of Coke

An output of 60 tons of pig iron per day with charcoal as fuel, 120 tons per day with anthracite as fuel, and over 1000 tons per day

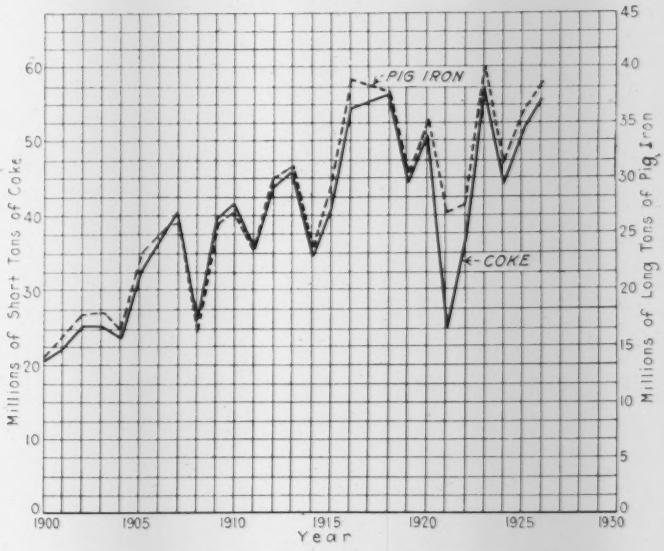

Fig. 1 U. S. Production of Coke and Pig Iron, 1900–1926

in the record coke furnace shows the progress which has been made in the pig-iron industry, and this is due largely to the quality of the fuel and modern carbonization methods.

The coking process in the United States, commencing in 1841 with the two McCormack and Campbell ovens and reaching 100 ovens in all by 1855, continued its rapid growth, and the records of the Geological Survey show that in 1880 the number of ovens had increased to 12,372. The number of beehive ovens reached a maximum in 1910, when there were about 100,000 in working order, but no new ovens of the beehive type have been built in late years, and the number abandoned each year is quite large. In 1926 only 55,000 beehive ovens were in existence. The by-product oven was introduced in 1893, and had increased in numbers to 4000 in 1910. The figures for 1926 are 11,300 by-product ovens.

In 1880 about 5,238,000 tons of coal were carbonized in the coke ovens with a yield of around 64 per cent of coke, something over 3,338,000 tons. Last year (1926) about 82,000,000 tons of coal were carbonized, yielding about 68 per cent, or 56,000,000 tons of coke. During this period the percentage of the total production of bituminous coal which has been carbonized has remained sensibly constant, averaging roughly 14 per cent of the total, and only going below 10 per cent in 1884 and 1921, periods of business

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Contributed by the Fuels Division and presented at the Spring Meeting, White Sulphur Springs, W. Va., May 23 to 26, 1927, of The American Society of Mechanical Engineers.

depressions and strikes. The percentage of bituminous-coal consumption, as contrasted with production, has even been more constant at around 15 per cent. The curve to some extent reflects increasing efficiencies of yield, which have increased from 64 per cent to 68 per cent with the improvement of the by-product oven.

Taking the period from 1915 to 1926, including both years, the average tonnage of coal carbonized has been around 73,000,000 tons, the trend being slightly downward. The coke made has averaged around 48,000,000 tons, the trend being in the opposite direction. These years reflect the intense activities of the war period coupled with the business-depression and labor-readjustment period of 1921–1922.

The Beehive Coke Oven

The original ovens built by McCormack and Campbell in 1841 were of the beehive type and about 8 ft. in diameter, a simple brick chamber shaped like a charcoal kiln with a hole in the top for charging and the escape of the products of combustion, and a door on one side to supply air for combustion and through which the coke was drawn when the process was completed. The charge was around two tons, and the yield of coke about 50 per cent. Many attempts have been made to improve the beehive oven, but it remains substantially as when first introduced in all respects except dimensions. The standard beehive oven is 12 ft. in diameter by 7 ft. high, and the normal charge is around $7^1/_2$ tons, yielding about 4.5 tons of coke per charge. At least four full days were necessary for the coking operation, and this time has not been materially reduced, although good 48- and 72-hr. coke has been made in the beehive oven. The usual practice is two charges per week with 48-hr. coke, and one charge with 72-hr. coke. There are a few ovens of rectangular types which take a larger charge. The year of maximum production was 1916 when 55,159,460 tons of coal were carbonized, yielding 35,464,224 tons of coke. The beehive oven last year carbonized 18,100,000 tons of coal, yielding 11,500,000 tons of coke. At the present time the beehive oven is the flywheel of the coke industry, supplying the fluctuations in demand.

Development of the By-Product Coke Oven

It has long been known that the coking process as practiced in the beehive oven was wasteful, and many attempts have been made to utilize the wasted heat in a more efficient manner. Fulton in his treatise on coke has given many examples of these attempts, but this type of oven did not readily lend itself to innovations, and only the simple type has had a continuing existence. In Europe where coal was more costly and the necessity for saving more apparent, these early attempts to improve the beehive oven led Simon-Carves and others to experiment with other forms of ovens in which the carbonization process could be carried on in a shorter time without affecting the quality of the product and to which the (at that time) new ideas of recuperation or regeneration could be applied. Incidentally, it was found that valuable by-products might be saved in such quantities as to pay a portion of the construction and operating costs of the process. In France, Germany, and England these experiments were successful, and in 1893 the Solvay Company built the first bank of by-product coke ovens in this country. These ovens were about 30 ft. long, 6 ft. high, and about 24 to 30 in. wide, and took a charge of 8 tons of coal. The time of coking was also much shorter. Improved types of the new design were introduced with great rapidity, 4000 ovens being in use in 1910 and 11,300 in 1926. In 1915 about 19,550,000 tons of coal were carbonized in the by-product oven yielding 14,072,895 tons of coke, while in 1926, 63,700,000 tons of coal were processed with a yield of 44,500,000 tons of coke.

As long as the carbonization process was carried on in ovens approaching the beehive type, no by-products were saved and attention was centered on the quality of coke, even though the yield was perhaps lower than it should have been. With the advent of the by-product oven, the coke yield improved and the coking time shortened. The earlier by-product ovens were more or less imperfect in their heating arrangements and the coke quality was not quite so good as with the beehive oven, but this condition was soon corrected, and today 80 per cent of the coke supply is manufactured in the by-product oven. The width of the oven has been decreased to about 14 in., and most of the coke is made in from 14 to 16 hr., while improvements in handling and quenching have improved both yield and quality.

Better designs of regenerators and methods of heating have made savings in the quantity of gas used to heat the ovens, increasing the quantity of surplus gas, which is being used more and more as a fuel in the open-hearth process with excellent results. Very large quantities of tar are also used for open-hearth and other furnace firing, less than half the output being sold to the tar-distillation companies. The other by-products are ammonium sulphate and light oils.

The Ammonium-Sulphate Situation

Analysis shows that American coals vary in nitrogen content from about 0.50 per cent to nearly 2 per cent, corresponding to a theoretical range of from 47 to 188 lb. of ammonium-sulphate equivalent per ton of coal processed. The recovery varies between 10 and 30 lb. Some of the nitrogen goes into the tar as pyridine and allied compounds, the remainder being lost in the coke and gas as elementary nitrogen or cyanic compounds.

The supply of inorganic nitrogen in the United States in 1926 was about 282,000 tons of nitrogen content. Roughly 38 per cent of this is represented by the ammonium sulphate equivalent furnished by the carbonization of coal, 56 per cent by the imports of Chilean saltpeter, 2 per cent by other nitrogenous imports, the remaining 4 per cent being furnished by the various systems of air fixation. Domestic use in fertilizers accounts for 36 per cent of the total, with 24 per cent exported. The explosive and chemical industries use about 12 per cent, while the remainder, 28 per cent, is used as ammonia, mostly in the refrigeration industry. With the growth of the by-product production the importation of Chilean nitrates has been decreasing, although large quantities are required for the nitric-acid industry, which produces about 80,000 tons of 100 per cent acid every year.

The production of the ammonium-sulphate equivalent has been steadily increasing and amounted to around 700,000 tons in 1926. The price of nitrates in Chilean saltpeter has determined the values of ammonium sulphate, which is usually quoted at around $50 per ton, hardly enough to pay for the sulphuric acid and cost of manufacture. Should the price of Chile saltpeter fall materially on the conclusion of the producers' agreement this summer, the market for ammonium sulphate may be very seriously affected.

The oils saved in the by-product process are sold under a variety of names, the most important, benzol, competing with gasoline. The price has been subject to wide fluctuations of late years, and follows the gasoline price. While most of the coke produced is used in the blast furnace and cupolas of the metallurgical industry, a steadily increasing amount has been sold as domestic fuel.

The Domestic-Fuel Situation

The eastern United States has been singularly blessed in the large domestic fuel deposits of anthracite occurring in northeastern Pennsylvania. These deposits have furnished in the last century more than 3,000,000,000 tons of the best-quality smokeless domestic fuel, and it is estimated that a nearly equal amount will be produced in the next hundred years in diminishing yearly yields. This fuel is already commanding a luxury price and the domestic consumer has turned to by-product coke, oil, and gas as substitute fuels. Bituminous coal is also used as domestic fuel, particularly in those sections east of the Rocky Mountains and at a distance from the source of anthracite supply. All other deposits of anthracite in coal-producing countries are of poorer quality and of small importance, furnishing in total less than one per cent of the world's fuel supply. The domestic use of solid fuel keeps pace with the increase of population, roughly at a rate of about 2100 lb. per capita per year, and the domestic use varies from 15 to 20 per cent of the total anthracite and bituminous-coal production. The use of by-product coke, natural gas, and fuel oil has been increasing, but has not as yet produced a marked change in these proportions.

Superiority of High-Temperature Coke

The processes for the carbonization of coal used in the beehive and by-product ovens are by their nature high-temperature processes;

indeed the tendency is toward higher temperatures, since the most valuable product, coke, when made under high-temperature conditions, appears to work much better in the blast furnace.

In a paper read before the International Conference on Bituminous Coal, in Pittsburgh, F. F. Marquard, superintendent of the Clairton plant of the Carnegie Steel Company, presented a brief summary of results obtained recently in operating his plant at varying oven temperatures. The entire group of 1500 ovens, which form the largest coke plant in the world, was operated for considerable periods of time at various temperatures, by steps of 50 deg. from 1600 deg. to 2100 deg. fahr. Twenty-four blast furnaces are regularly supplied with coke from this plant, and the behavior of these furnaces in the manufacture of pig iron was observed with the cokes made at these different temperatures. It was concluded that almost universally the superior furnace performance was obtained with coke made at the higher temperatures. The superior performance consisted of both greater iron output and greater fuel efficiency. It was while using coke made at 2100 deg. fahr. (oven-wall temperature) that one of the blast furnaces of the Steel Corporation made its world's record of production. This production on a 30-day average was 823 long tons of pig iron per 24 hours; and this tremendous output was reached with only 1825 lb. of coke per long ton of pig iron made. Single-day records of over 1000 tons were reached. These records have been exceeded since Mr. Marquard presented his paper.

Low-Temperature Carbonization

In Europe the by-product-coke industry has been drawn upon for the domestic fuel, but in England the demand for an open fire had led to many experiments in the production of a smokeless domestic fuel more suitable for use in open grates. By-product coke is nearly devoid of volatile matter, due to the high temperatures used and the time of coking, and the English demand for a flaming fuel might be met by a coke made at a lower temperature in a shorter time, hence the development of low-temperature carbonization processes in which a domestic fuel with from 5 to 12 per cent of volatile matter is the main product. This kind of carbonization process yields much larger volumes of tar, less gas, and very little ammonium sulphate. The light oils and tars appear to promise a source of motor spirits, and a possible source of lubricants, which together with the smokeless fuel has induced the British Government to finance many of these researches. Dr. C. H. Lander, Director of the Fuel Research Board of Great Britain, at the International Conference on Bituminous Coal, at Pittsburgh, last year, made the statement that the low-temperature carbonization process in England was now on a commercial basis. At least two different processes with a capacity of 200 tons per day are in continuous operation, while other installations are in contemplation. A number of smaller plants are in operation in Germany. Numerous experimental plants have also been built in the United States. These processes are of two kinds: the first where the heat is applied outside the retort and the process resembles Scotch oil-shale retorting, and the second where the heat is applied inside the retort directly to the coal to be carbonized, and the process resembles in a greater or lesser measure the bituminous producer, where the coke is removed continuously, the products of combustion mixing with the gas produced. In a third category may be included all the complete gasification processes which are not particularly coal-carbonization processes.

Carbonization may take place at very low temperatures. Parr reports in his experiments a certain giving off of gas at as low as 250 deg. fahr. The commercial low level is 660 deg. fahr., and from here to 1300 deg. fahr. is the field of the low-temperature process. Above 1300 deg. fahr., all coking may be termed high-temperature up to the 2100 deg. fahr. wall temperature reported by Mr. Marquard. Temperatures in parts of the beehive and by-product ovens are probably much higher than the 2100 deg. fahr. reported by him.

Yields from Carbonization Processes Compared

Low-temperature carbonization has been in use in some of its many forms for a considerable period, and with varying degrees of success, but generally in connection with some large industrial or metallurgical plant. In general, all low-temperature processes may be classified as:

1 Externally heated retorts
2 Internally heated retorts
3 Complete-gasification processes.

The average yields per ton of coal of each type is given in Table 1, where Type 4, that of the average high-temperature process, is given for comparison.

TABLE 1

	Type 1	Type 2	Type 3	Type 4
Gas, cu. ft. per ton	5200	35,000	112,000	11,000
Ammonium sulphate, lb. per ton	18	22	45	25
Light oil, gallons	2.5	2.0	3.0	2.5
Tar, gallons	18	16	24	12
Capital cost per ton daily throughput	$2500	$2400	$1900	$2500

These figures are averages of many experiments, and large variations exist between individual processes and individual coals. Using the same coals, it is well to remember in the face of some promotion enterprises that no processing can increase the heat yield per ton of coal, and except for a probable slightly better heat balance in the low-temperature processes it should be remembered that the individual processes differ only in the distribution of heat units between coke, gas, tar, and radiation.

Low-temperature carbonization obtains more tar at the expense of less gas than the high-temperature process; also, the lower temperature yields less ammonia, and through the absence of cracking a gas of higher thermal value which naturally yields more light oil on scrubbing. The refining loss is also higher because of the larger quantity of unsaturated hydrocarbon compounds.

Retorts for Low-Temperature Processes

Low-temperature carbonization has been practiced in a great variety of retorts, but in general they can be assigned to one or more of the following classes: Static or dynamic; internally or externally heated, or both; vertical, horizontal, or inclined. In some cases the coal is briquetted before coking, in others after coking, and still others between primary and secondary coking. In some cases the coal is not briquetted at all, and in some cases it is finely pulverized. A great number of coals from all over the world have been tested in low-temperature experiments, and retorts have been developed in nearly every important country.

Obstacles to Low-Temperature Coking

The great obstacles that have hindered progress in low-temperature coking are (*a*) mechanical difficulties and (*b*) thermal difficulties. The mechanical difficulties have arisen through the necessity of handling hot, sticky, plastic materials, and the evil of hard, graphitic deposits. The thermal difficulties arise through the reduced temperature gradients and resultant troubles of heat transfer. Neither of these difficulties has been surmounted, but efficient design is progressing toward the solution of the one, and the recognition of certain principles such as that of using thin layers of coal to facilitate heat transfer is pointing to the solution of the other. The use of thin layers, however, brings forward another problem: the multiplicity of retorts with attendant high labor costs, high maintenance, and difficulty of bulk processing.

The financial status of low-temperature coking is closely allied to its economic aspects. The coke in most cases is too fragile for blast-furnace use; in some cases it is fit for foundry use, and in the domestic fuel market it must compete against its own raw material, bituminous coal. It is claimed that the great outlet for low-temperature coke is the electric central stations where the yield of by-products may be credited to lowering the fuel cost. The disposal of large quantities of gas is also a perplexing problem. Low-temperature tar, after the extraction of light oil, is at present of questionable value. Tar distillers are doubtful of its value to them, but some authorities hold out hope of utilizing its high creosotic content in the wood-preserving industry. The only assured market is that of a fuel oil sold on a B.t.u. basis. The ammonium sulphate will probably realize a small profit, but the effects of large quantities upon the market cannot be predicted. Little difficulty should be encountered in disposing of light oil as motor fuel.

The By-Product Process in Connection with Electric-Light and Power Central Stations

The best discussion of the by-product process in connection with

the electric-light and power central station was written by Dr. G. Klingenberg under pressure of war times and given to the Verein Deutscher Ingenieure in 1917. Just before his death he embodied the major part of the discussion in the 1924 edition of "Bau Grösser Elektrizitätswerke." After a rather full consideration of the national demand for by-products of the carbonization of coal and the resultant values, he worked up the economics of a number of schemes, including both steam and gas plants under various conditions of coal and by-product prices, and came to the following conclusions as to their value under the conditions obtaining in Germany.

a "The direct firing of coal is always superior to its gasification when coal costs more than $1.50 per ton and when the income from by-products amounts to less than $1.62 per ton. (The higher the price of coal, the less are the prospects for the erection of a plant for gaining by-products economically.) From this we conclude, firstly, that by-product plants (with producers) for German bituminous coals having small nitrogen contents are not feasible. Also coals having an average content of nitrogen can only be gasified under the assumption that the sulphate price remains at normal height.

b "As long as the coal price lies under $3.50 per ton, by-product

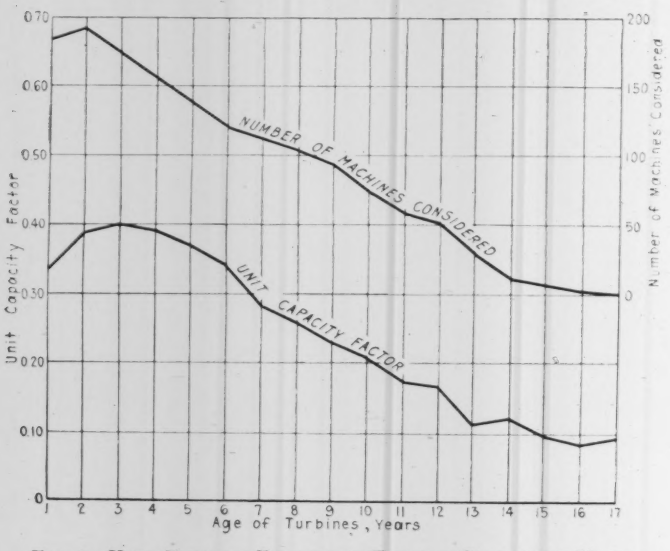

FIG. 2 UNIT CAPACITY FACTORS OF TURBINE-GENERATOR UNITS
(Total number of units reported on, 268; Minimum size, 750 kw.; Maximum size, 60,000 kw.)

plants work more economically in connection with steam turbines than with gas engines.

c "Gas-engine plants come into consideration only when coal is higher than $3.50 per ton and when the income from by-products amounts at least to $2.50 per ton of coal.

"The load range within which direct firing has preference is the greater the less is the by-product income. The direct firing of coal is, for all load conditions and reasonable coal prices, the cheapest kind of operating as long as the income from by-products is less than about $2.00 per ton of coal processed."

Klingenberg's figures were very carefully made for three types of plant, with a number of assumed coal prices and by-products yields as well as prices. Fixed charges were taken into account as well as operating charges, and in general the study is a model of careful, painstaking work. Dr. Klingenberg stated in public before the Society on his visit to America in 1924 that he saw no reason at that time to change the general conclusions reached in his 1917 paper. He brings out the well-understood fact that with the saving of by-products much more coal will be used. He says: "The repeated assertion that the direct burning of coal without saving of by-products represents a vast waste of fuel and of the national wealth, is therefore misleading. The coal indeed contains important and valuable ingredients that are destroyed, but against this there is a distinct conservation of our coal resources." The paper brings out clearly another well-known but considerably neglected fact: All coking and by-product operations are continuous operations, 100 per cent load factor, when conducted in quantity, and variations in output are only secured at a prohibitive expense. Power and lighting loads on the contrary are variable-output operations, and system load factors higher than 50 per cent are unusual. His diagrams show clearly the unfortunate effects of a low or variable load factor on the by-product plant.

BASE-LOAD CENTRAL-STATION PLANTS

Base-load central-station plants are possible and some few plants of this character are in existence, although the load factors are not of the order of 100 per cent, and the maximums have not exceeded about 80 per cent. Junkersfeld[2] in the discussion of the author's paper on the Commercial Economy of High Pressure and Superheat in the Central Station, presented at the Annual Meeting of the A.S.M.E. in 1922, brought out the fact that the capacity factor of turbines five years or more old in most of the best-operated companies had dropped to 32 per cent, showing definitely that base-load operation would at least be limited to less than that time. Alden in the report of the Committee on Power Generation, presented to the A.I.E.E. in 1925, says: Each new turbine or station operates on base load only for so long a time as it constitutes the most efficient turbine or the most efficient station generating power for that particular system." The curves, Figs. 2 and 3, show this

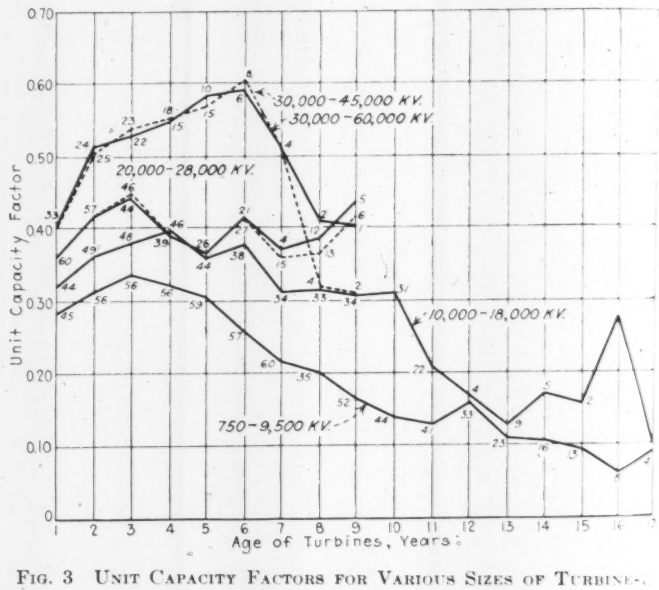

FIG. 3 UNIT CAPACITY FACTORS FOR VARIOUS SIZES OF TURBINE-GENERATOR UNITS

in a very striking manner, and these curves represent the actual operating history as regards kilowatt-hours generated during successive years by 268 turbines ranging in size from 60,000 kw. down to 750 kw. Nevertheless, problems of this nature are being studied by the engineers, and the paper by Runge, presented at the International Conference on Bituminous Coal in Pittsburgh last year, is descriptive of the first experimental plant of this kind in the United States.

CONCLUSIONS

High-temperature carbonization processes are of long standing and well established; their position in the economy of the metallurgical industry is assured. The weight of the evidence indicates that this method will continue to be the main source of metallurgical fuel for many years, and that a portion at least of its output will be diverted as solid fuel for household use. With regard to the low-temperature processes, the consensus of opinion shows that economic results have been obtained in England where the demand for household fuel of a peculiar character is good and prices are high enough to be attractive. In Germany the demand is of a different nature and the brown-coal processes are attractive, but for other reasons. In most of the western European countries high-temperature processes have the same vogue as in the United States for metallurgical purposes, but other processes not essen-

[2] Trans. A.S.M.E., vol. 44 (1922), p. 1157.

tially carbonization processes are being developed to supply the demand for tars, oils, and motor fuels, which are scarce and costly as compared with similar products in this country.

The work of research and experimentation is proceeding in considerable volume, but commercial success is a function of demand which must be built up, and higher prices which may come with the depletion of our oil supplies with which a portion of the product must compete.

Meanwhile, the improvement in the economy of power generation has been such that processed fuel is not as attractive as was the case at the time Klingenberg's paper was written. Load factors have not greatly improved, although advantage has been taken of all available diversity. The best commercial results are still secured with generation as close as possible to the centers of heavy demand. In general that combination of fixed charges, overhead, and operating cost secured by the simpler combination, with the fewer chances of interruption and loss, insures continuous service and an adequate return, which is the best criterion of the economic advantages of an industry to the country as a whole, and to that portion of the public supporting the industry.

Discussion

H. D. SAVAGE[3] wrote that in view of the amount of time, energy, and money that had been spent on low-temperature carbonization since Dr. Klingensberg's statements in 1924 on the economics of the process, they could not be taken very seriously, nor his dogmatic statements as to when direct firing was superior to low-temperature distillation. His statements that the disposal of large quantities of gas was a perplexing problem, that low-temperature tar, after the extraction of light oil, was of questionable value, and that its only assured market was as fuel oil when sold on a B.t.u. basis also could not be taken seriously. While agreeing with his statement regarding the well-understood fact that by the saving of by-products, more coal was used, it was least of all possible to agree with his statement, "The repeated assertion that the direct burning of coal without saving of by-products represents a vast waste of fuel and of the national wealth is therefore misleading."

To show the fallaciousness of all these assumptions in regard to low-temperature distillation, he presented an analysis recently made in connection with the Jordon Power Plant, closely adjacent to the City of Salt Lake, wherein it had been suggested that a low-temperature distillation plant would be profitable. This plant burned about 65,000 tons of coal per year at a cost of $3.05 per ton delivered. In order to get the equivalent in char of the 65,000 tons of raw fuel used per year, it was necessary to carbonize 93,000 tons of coal. The coke to be burned in the power plant on the basis of a 70 per cent yield was worth $2.135 per ton on a percentage basis. There would be 25 gallons of tar per ton, with an established market value in that vicinity of 7 cents per gallon, a return of $1.75. The 4000 cu. ft. of gas could be wholesaled to the gas company at 30 cents per thousand cubic feet, thus returning $1.20. The $3\frac{1}{2}$ gal. of motor spirit, at 14 cents a gallon, would add 49 cents. Thus the by-products would yield $5.575 per ton of coal. At a cost of $1.055 for expense of carbonization including interest and depreciation plus $3.05 for coal, the total cost would be $4.105, leaving a net revenue of $1.47 per ton or $136,500 per year, a 39 per cent return on the $350,000 investment necessary for the plant. With the KSG or Essen System, producing domestic fuel, the return with the by-products figured just as conservatively as the above, would net about $3.50 per ton processed.

Mr. Savage then attacked the problem from the conservation point of view. It was true there had been mined 18,000 tons of coal more than would have been mined had the coal been burned in a raw state. This coal had a delivered value of $54,900, but there were returned as a by-product 370,000,000 cu. ft. of gas, which was only 82 per cent of the present yearly consumption of Salt Lake City and had a wholesale value of $111,000. On a fair basis, in a most modern gas plant, under best practice, and with best gas coals, conditions which it was reasonable to assume did not exist in this plant, this amount of gas would have necessitated the use of 7400 tons of raw coal plus a certain amount of fuel oil necessary for gasification. The coal alone would have a delivered value of $22,570, so that the cost for excess fuel was only $32,330, less the necessary fuel oil for gasification purposes. In addition 2,300,000 gal. of tar worth $161,000 and 325,000 gal. of motor spirit worth $45,500 were obtained so that by mining 10,600 additional tons of coal worth $32,300, recovered raw by-products worth $317,000 were obtained. From this tar, 100,000 to 150,000 gal. of crude motor spirit could be obtained. There would be 930,000 gal. of oil suitable for disinfectant purposes, sheep dips, and flotation purposes, for which there was a ready market within a short radius of the particular plant.

The McEwen-Runge system, which was being developed purely as an adjunct for power-plant work, did not have to work on a 100 per cent load factor, but could be efficiently carried on at varying ratings necessary for coördination with power-plant demand. It was quite true, wrote Mr. Savage, that by the old method of washing with sulphuric acid, the loss was high due to the unsaturated hydrocarbons, but it was well to remember that nowadays the specification for a water-white gasoline was no longer urgent and it was a well-known fact that some of the so-called unpurified gasolines, which on standing turned a slight straw color, actually gave more mileage and more power than the water-white product.

Low-temperature tar contained per gallon much more oil and much less pitch than did high-temperature tar, as well as products that were not found in high-temperature tar. Dr. Muller of Germany, who had handled the low-temperature tar from the KSG process, had put a value on it in Germany of nearly 14 cents per gallon.

It was only necessary to review the quantities of cresols and phenols that were used in this country to realize in a way the value of low-temperature tars. These tars contained a very high percentage of tar acids, which were made up of phenols, cresols, and other members of the same family, and on distillation the oils contained as high as 35 to 40 per cent of these tar acids. It was relatively simple to extract the tar acid from the oils so that they could be used in a large number of industries such as the bakelite industry, disinfectant trade, and the wood-preservation and flotation uses.

In addition to the tar acids which were found in many of the fractions from low-temperature oils, there were also found compounds known as neutral oils. Experiments such as have been carried on in Germany on this type of product proved very conclusively that these oils made an excellent fuel for internal-combustion engines. In fact, there were so many ramifications for the possible use of low-temperature tar and its distillates, far beyond those of the high-temperature product, that it seemed almost ridiculous to state that the tar must be sold on a B.t.u. basis.

Mr. Orrok had also stated that the disposal of large quantities of gas was also a perplexing problem. It must be remembered that the demand for gas doubled every ten years and that if low-temperature plants were not put in to take care of the increased gas supply other means must be provided. Furthermore, the quantity of gas produced per ton was approximately 50 per cent of that produced by high-temperature processes, so that no danger of flooding the country with gas was felt. He disliked to see an engineer of Mr. Orrok's unquestioned eminence so pessimistic concerning the economic value of that which, to his mind, was one of the greatest economic industrial advances since the commercial establishment of pulverized fuel, and he wanted to assert that the KSG system, upon which many years of effort and vast sums had been spent in Germany, had been considered a commercial operation at Essen for the last three years, and that the McEwen-Runge system was, barring a few minor mechanical details, now in what might be considered practical, commercial operation at Milwaukee.

L. Pendred[4] said that the author had not mentioned one man who apparently had been almost forgotten in this country, but whose influence on coal carbonization in Great Britain had been very considerable; one Thomas Parker, of Wolverhampton, who patented what was called the Coalite process. His intention was to produce a fuel which was half coke and half coal by a low-temperature distillation process. The fuel was to be sold for domestic purposes and the gas produced in the manufacture of it was to be used by the gas companies. The gas companies would not take it up and Thomas Parker lost a great deal of money.

[3] Vice-President, Combustion Engineering Corporation, New York, N. Y. Mem. A.S.M.E.

[4] Editor, *The Engineer*, London, England.

Some years ago Dr. Beilby, an eminent fuel chemist, in discussing this question, came to the conclusion that low-temperature carbonization in England at any rate could never be successful. He showed, Mr. Pendred thought, that there would be a loss of three to four cents per ton of fuel consumed.

In Great Britain, many experiments on low-temperature carbonization were being carried out and Dr. Lander had said that they were now on a commercial basis. That might be so, but the commercial basis was such a small one and the product was so small that they were very little more than laboratory experiments. He thought that it would be unsafe at the present time to say definitely that low-temperature carbonization was an economic proposition.

W. Trinks[5] spoke of the development of by-product coke plants during the War and of the value of the toluol and benzol.

Today, although the market for benzol, toluol, and ammonia was not as good as it was during the War, the steel plants recognized the value of coke-oven gas and tar as fuels for the open-hearth and heating furnaces. The use of coke-oven gas and tar did away with many gas producers. Gas producers had to use a good gas coal and good gas coal was becoming scarcer all the time. Furthermore, there were coal handling, ash handling, gas-producer labor, and very often bad gas to contend with, all of which was overcome by the introduction of by-product coking because by-product gas and tar could be pumped directly to the open-hearth furnace. Living in a district where benzol was made in large quantities, Professor Trinks had found that benzol did not compete with, but supplemented, gasoline inasmuch as it was mixed with gasoline and gave to it properties which very largely did away with detonation. Professor Trinks felt that there was a great field for the smokeless fuel from low-temperature carbonization processes in the central states where smoky coals had to be used domestically.

A. E. Forstall[6] said that if a low-temperature carbonization process could be made to pay 39 per cent as H. D. Savage had said, it would need no advertising but would sweep over the country and be adopted everywhere. It was well to call attention to the fact that up to the present time no carbonizing plant in the United States had been successful from the financial point of view except those which were connected with steel plants or those which had built up a domestic trade. He felt that it would be necessary for low-temperature plants to build up a domestic business with a high price on their fuel.

The author was right in saying that the choice between high- and low-temperature carbonization processes was a question of which was worth the more. The relative merits of the two plants depended entirely upon the cost of installation in any particular case and the return from the different kinds of production.

George Orrok had said that the by-product industry had started on ammonium sulphate and was built up on ammonium sulphate. Today in the United States ammonium sulphate sold for fifty-three dollars a ton with a profit of a dollar a ton. If the price dropped to fifty-two dollars, the profit was wiped out. At fifty dollars the loss was two dollars a ton. In England it cost about forty dollars a ton to make sulphate and it sold at the same price as in the United States. In Germany it sold at the same price as in the United States and it cost thirty dollars a ton to make. There was a large profit in Germany, a somewhat smaller profit in England, and in America a profit that could be wiped out by a single point on the market.

Further, ten thousand tons of ammonium sulphate put on the market would reduce the price in America to forty-eight dollars. Every coke-oven plant knew this and doled the ammonium sulphate out in small lots, taking care not to break the market.

A. G. Christie[7] said that in the early days of the development of the steam turbine, everyone was a pessimist about its success. It seemed to be the same at present in connection with low-temperature carbonization. He did not feel quite so pessimistic about the outlook. He had been following the different processes quite closely and while there were difficulties ahead, and while there might be many problems ahead and mistakes still to be made, it seemed to him that we were approaching more closely to commercial development. He felt that some of Mr. Savage's figures were optimistic, particularly the price of the gas, because gas was being bought at wholesale in Baltimore from a by-product gas plant at a figure below the one quoted. The low-temperature carbonization process would have to stand largely on the ability to furnish fuel to domestic users.

Dr. Klingenberg had pointed out that the opportunities for by-product propositions were greatest where fuel cost was lowest. Applying this to the coal fields of the United States showed that the possibilities of low-temperature carbonization should be greatest in the Middle West where fuel costs were lowest and where the lowest grade fuels were located.

Nevin E. Funk[8] said that he was interested in the application of low-temperature carbonization to power plants. If an attempt were made to load all the central stations in the country with the low-temperature carbonization process, the market would be ruined for everything except the gas and the coke which might have to be burned in the plant in order to get rid of it.

If the coke was a domestic fuel, which from the discussion it seemed to be, then the gas that remained must be sold to the gas company. Why, then, was not the low-temperature carbonization process a gas company's process and not an electric company's process?

He believed that low-temperature carbonization could not be considered a cure-all for the supply of power. It undoubtedly would fit into specific niches, and there was no question but that the development would progress to a point where it would be successful.

John T. Wilkin,[9] speaking for the consumer, said that people living in the soft-coal regions of the Middle West were eager to get a smokeless fuel and were willing to pay more for it than for their local coal. He had bought briquets from Fairmont, West Virginia, for use in his own house.

Walter N. Polakov[10] said that from the point of view of the fuel consumer, it was well to remember that the consumption of domestic fuel was many times larger than that of central stations and stationary power plants. Nobody was looking for a panacea but for the adoption of the most economical process and the one most suitable for the particular field of application. His personal experience with the domestic use of low-carbonization coke or briquets had been favorable.

He had had considerable experience with annealing furnaces, particularly annealing brass and bronze, in which low-carbonization fuel proved superior to any other fuel, and in one instance he had burned it in a Murphy stoker, under high-pressure, boilers, with loads varying from 60 to 120 per cent of rating, and with a boiler efficiency of from 3 to 5 per cent higher than the average obtained when burning New River coal.

The author, in a closure to the discussion, called attention again to the question of power factor in the operation of low-temperature carbonization plants in central stations. In New York City, he said, a base-load plant was an impossibility.

Mr. Polakov had brought up the interesting question of consumption of solid fuel. As he had said in his paper, the consumption of solid fuel for domestic purposes had been constant for the last fifteen or twenty years at about 2100 lb. per capita. The central-station use had been of the order of 45,000,000 tons for the last eight or ten years. While the kilowatt-hours of output had increased, the use of coal itself as a fuel had been, if anything, a little smaller each recurring year, and the pounds of coal per kilowatt-hour had been very markedly reduced. About 40,000,000 tons of coal were used by the central stations, about the same amount in complete gasification processes in the metallurgical industry, about four to five times as much in domestic use, and about four to five times as much in railroad use.

He also emphasized the fact that in any carbonization process, any complete gasification process, any plant in which coal was the raw material and power or by-products or domestic fuel were the result, the question was one of economics, and economics alone.

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[5] Professor of Mechanical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa. Mem. A.S.M.E.

[6] Forstall, Robinson and Luqueer, New York, N. Y. Mem. A.S.M.E.

[7] Professor of Mechanical Engineering, Johns Hopkins University, Baltimore, Md. Mem. A.S.M.E.

[8] Operating Engineer, Philadelphia Electric Co., Philadelphia, Pa. Mem. A.S.M.E.

[9] President, Connersville Blower Co., Connersville, Ind. Mem. A.S.M.E.

[10] President, Walter N. Polakov & Co. Mem. A.S.M.E.

American Fuel Resources

Growing Appreciation of the Value of Fuel—Various Fuel Resources—Solid Fuels Our Main Source of Energy—Coal Resources Economically Available Less Than Generally Believed—The Passing of Anthracite

By O. P. HOOD,[1] WASHINGTON, D. C.

THE fuel resources of America can be referred to in a general way as not only abundant but as superabundant. No lack of fuel for warmth or industrial development has so impressed itself on our people as to form habits of high appreciation of fuel. On the contrary, our habits have reflected a general indifference to the significance of fuel in our modern life. Until the experiences of the late war we were annoyed when some temporary or local condition raised the price of fuel to what seemed a high price. While other peoples shivered through a winter our homes were overheated, and we dressed almost as in summer. We have never had to think of quilted and padded garments, as worn by the Chinese, nor of unheated living quarters, so common in Europe. While other peoples conduct great industries using fuel whose heating value, pound for pound, is less than half that of ours, we use the finest coals on earth indiscriminately for general purposes. For generations our fight was to rid the land of the forest, and we burned remorselessly. The cheapest immigrant labor was used to develop our abundant coal fields, and it was frequently true that a load of coal could be delivered at our homes cheaper than a load of dirt. The passing of this phase of national thoughtlessness and wastefulness is to be expected. There are evidences of a new attitude of mind toward our fuel resources. Our forests are gone, cheap labor is no more, nations have fought for coal fields, and there is a growing appreciation of the part that fuel plays in furnishing the material blessings of our daily lives. Dr. T. T. Read has shown that, of all nations, we do half again as much work per individual as the next most active group, and thirty times more than the Chinese. This work comes largely from coal. We would each have to have thirty-five slaves who never ate, in order to have an equal energy supply.

Growing Appreciation of the Value of Fuel

Meetings such as this and the International Conference on Bituminous Coal, at Pittsburgh, last year, give evidence of a growing appreciation of fuel. That our great power houses have within a decade reduced to a third the amount of coal used per unit of output, is further evidence of this new appreciation. We have, however, but barely begun our movement in this direction, and fuel waste and inefficiency in use are common. Our fuel assets have been expressed in such tremendous figures that their enumeration has made us tolerant of waste, although we have evidence that even big figures have an end. Natural gas has come and gone in many communities. Our finest coking-coal district is depleted. A limit to the availability of anthracite is more than hinted. All of these facts give new meaning to an enumeration of our fuel assets. Proud of their immensity, we nevertheless propose to develop habits of rational use rather than of prodigal waste. This paper is to give a brief picture of national fuel resources, while most of the sessions of this meeting will deal with rational uses.

Our Bountiful Supply of Fuels

We have fuel in quantity in each major physical state—gaseous, liquid, and solid. No other nation has a more bountiful supply. As to natural gas, no attempt has been made to estimate the reserves in the ground of this fugitive form of fuel. We can record only the measurements, estimates, and guesses as to quantities that have been in the past reduced to possession. In 1925 a little over eight cubic miles of natural gas was delivered to consumers. This had the potential heating value of 35,000,000 to 40,000,000 tons of coal, or something less than a month's production of bituminous coal. In 1914 the production was about one half this amount. From 1915 to 1922 the rate of increase was slow, but it has been more rapid of late. Four states produce more than half of this quantity—Oklahoma, California, West Virginia, and Louisiana, so that the central, western, eastern, and southern portions of the country participate in this incomparable fuel. Over three and a half million domestic consumers enjoy its use. Of all our fuels the waste of gas is most obvious when it occcurs. A blowing or burning gas well announces itself. It is often produced far from an adequate market, and there is no feasible means of storage. It must be held in the ground until wanted if it is to be conserved.

Liquid Fuel Reserves

Our reserves of liquid fuel present an interesting study. Probably no one thing so typifies modern material life as the possession of means of quick and tireless individual transportation by auto or airplane made possible by the development of light, powerful internal-combustion engines using liquid fuel. This whole structure rests upon petroleum supply at present. A most careful inventory, as of January 1, 1922, placed the general order of magnitude of oil in the ground of the United States at about nine billion barrels. This is about as much as has been so far taken out up to 1927. We are therefore about half through with our original inheritance. If this remaining supply were used to paint the United States it would give a coat about seven-thousandths of an inch thick, what might be called a single-coat job. It would flood the state of New York something less than half an inch deep. A tank the size of the District of Columbia, and a little over twenty-five feet high, would retain it all. Since that inventory was made we have brought to the surface over a third of what was supposed to remain. If these estimates are anywhere near correct, it would seem that in the not-distant future something fundamental is pretty sure to happen. There are people, however, who have a sublime confidence that the estimates are wrong, and that no considerable change need be expected. With estimates of resources advising caution, with a growing willingness to conserve, we have at the same time an industry flooded with oil, and we are finding difficulty in devising effective precautionary means. It seems that we must enjoy the advantage of abundance while it lasts, and pay for extravagance later. The states of California, Oklahoma, Texas, and Arkansas produced in the order named 83 per cent of the total production of the United States in 1925. The future reserves lie largely in the Gulf Coast of Louisiana and Texas, the Mid-Continent field centering in Oklahoma, and in California, these districts holding two-thirds of the estimated nine billion barrels of remaining resources in 1922. Eighteen states are listed as producing oil in quantity. In no other country does petroleum play so large a part in the daily life of the individual as in this country. While its use as liquid fuel is most obvious, it may be that its most valuable service to humanity is in lubricating the wheels of industry, for which no substitute in quantity is in sight.

Solid Fuel Our Main Source of Energy

While gaseous and liquid fuels are in relative abundance, our main supply of energy comes from solid fuel. Were we compelled by lack to use the summer's crop for winter's fuel, as do some peoples, we have in straw and stalk an undeveloped and unappreciated supply that would fill but a fraction of our present needs. We use in many places wood for fuel, and sawmill waste presents an interesting fuel problem, but local in character. Had we large areas without either better fuel or cheap transportation, we might, as do the Russians, develop great peat deposits along our northern border and in our Gulf States. These resources lie fallow awaiting a different economic setting or undiscovered technical processes.

[1] Chief Technologic Branch, U. S. Bureau of Mines. Mem. A.S.M.E.
For presentation at the First National Meeting of the A.S.M.E. Fuels Division, St. Louis, Mo., October 10 to 13, 1927.

Peat is not produced in marketable quantities for fuel in the United States.

LIGNITIC COALS

Of lignitic coals next in order of development we have nearly a thousand billion tons. While this is a little less than a third of our reserve coal tonnage, and is perhaps a fifth of our heat reserve, coals of this sort play a relatively small part in present production. They are sure to play an increasing part in the development of states like Texas when oil and gas are less available, and North and South Dakota and Montana when larger demands are made on fuel supplies by increased population and industrial development. Arkansas lignite will be in closer competition with bituminous coal. The moisture content of lignite is from 25 to 40 per cent, so that roughly every third car when transported can be considered a car of water. Evidently, such fuel cannot stand the cost of distant transportation. When the water is removed by drying, the pieces break up into small sizes so that it is difficult to get air through a fuel bed. With the development of powdered fuel where lump coal has no form value, it may be possible by predrying to enlarge the range of usefulness of these lignitic coals. The present production of lignite is about 800,000 tons from the Texas fields, and about 1,200,000 from the northern fields. While the German brown coal so largely developed is lower in heating value than any of our lignites, it lends itself to cheap mining and also to cheap briquetting methods, because of qualities absent in our lignites.

BITUMINOUS COALS

Sub-bituminous coals have less moisture and lack the woody characteristic of lignite, but they lose moisture readily on exposure and break up into small pieces. Many western coals are of this type, some near lignite in quality, others nearly equal to the lower grades of bituminous coal. It is clean, of excellent appearance, and had we nothing better, great industries could be built on fuel of this quality, which is found in ten of the mountain states of the West, with more than half of it in Wyoming. In about one thousand billion tons which we have of this coal there is stored about 30 per cent of our future heat resources in coal.

The fuel of the country, however, more widely distributed, more largely produced, used by more of our people, and the dependence of our great industries is bituminous coal. Found in twenty-eight states east and west, north and south, it is perhaps our greatest material blessing next to fertile fields and a livable climate. Fourteen hundred billion tons is the estimate of available supplies, and in this form more than half our heat reserves in coal are stored. If reduced to a layer six feet thick it would cover all the states of Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, and Tennessee. Rich as is Pennsylvania with its hundred billion tons, West Virginia and Kentucky each have nearly a quarter more, Illinois twice as much, and Colorado two hundred and thirteen billion tons reserve. Utah is the farthest state west with a really great quantity of eighty-eight billion tons reserve. At present we are drawing upon these fourteen hundred billion tons at the rate of a little over half a billion per year, and the natural inclination is to divide one-half into the fourteen hundred and consider it unwise to worry about a tomorrow some thousands of years hence. This is an excellent illustration of wrong conclusions reached by the use of statistics that carry but a portion of the whole truth.

COAL RESERVES AVAILABLE AT PRESENT ECONOMIC LEVEL MUCH LESS THAN GENERALLY BELIEVED

The abundance of ice in the Labrador current can hardly be called a commercial asset to cool the summer's heat in New York, although not so very far away. To reduce such an asset to possession at the point, and when wanted, far outweighs its mere existence. What is computed in these tremendous reserves includes thinner seams, deeper lying and more distant beds than are now commercially of use. Our reserves of coal available at our present economic level are a very much smaller quantity. The rapid increase in the amount of fuel used per capita is likely to continue for some time. In 1870, 0.85 ton per year was sufficient for each individual. In 1925 it took 5.15 tons. If our supply of liquid fuels should fail the load would probably be thrown on coal supplies. The chemist is busy building new and old compounds from the elements which he is learning to control. The most obvious source of carbon in great quantity is from coal, and by it he will also probably get his hydrogen. Great industries based on the synthesis of such elements seem in the offing, and if they materialize it means more coal production. Dr. Geo. Otis Smith, Director of the U. S. Geological Survey, indicates a far more rational attitude toward our fuel supplies:

> The fact that more than half of the world's coal reserves are believed to lie within the territory of the United States has led too many of us into unwarranted optimism. The captains of the great industries concentrated along the Atlantic seaboard will do well to think less of the millions of tons that are said to lie awaiting their need in various parts of this continent-wide country of ours, but rather to ask for details as to where this coal is and how available it is for the use of this and the next generation. The total tonnage involves strings of figures hard for us to comprehend, but the tonnage remaining in the great producing fields of the East is so limited as to compel us to foresee their exhaustion within periods of the same magnitude as those which you executives figure as the expectancy of life for your industrial enterprises. For example, the Pittsburgh bed in Pennsylvania was estimated forty years ago as good for thirty generations, but the rate of mining has so greatly increased that now we must measure the exhaustion of this largest bed in the Keystone State by the space of a single generation. This is not an exceptional illustration of the shortened life due to unexpected increase in drafts upon our coal resources, for in the Georges Creek field in Maryland this same bed, there called the "Big Vein," was believed forty years ago to have a life of at least 150 years, but today the field is regarded as almost worked out. Even if you turn to a less nearly exhausted field, such as the Pocahontas, the earlier optimistic calculations of an expectancy of life of four or five generations are now reduced to three or even two.

ANTHRACITE

Two other types of coal remain to be mentioned. When these great deposits of plant growth began their slow evolution they were full of water and of materials readily gasified at temperatures below the combustion point. By elimination and by slow combination these elements have been reduced by progressive steps and accompanying physical changes until with moisture nearly eliminated and volatile matter below 8 per cent, we have that aristocrat of fuels, the incomparable anthracite. In a paper on fuel resources the case of anthracite is a fitting foil to our over-optimistic consideration of unintelligible figures in thousands of billions. The anthracite measures of Pennsylvania probably held about 21 billion tons. In some districts this was practically the only kind of coal in use, and the only kind considered usable for domestic purposes. It was reasonably cheap, abundant, and highly effective. About four billion tons have been removed. Districts and services that were distinctly anthracite now use a greater quantity of other kinds of fuel. The price can no longer be called cheap; its distribution is not so general; the veins of highest quality have been worked out, and the disturbances and dislocations due to a necessary change in fuel habits of a large number of people have been real and profound. Probably something like 17 billion tons remain, and extraction will continue for years to come, but whatever the time may be, the end of the industry is at least within an understandable period of time. There is probably no better solid fuel for house heating in the world than anthracite coal, having less than 10 per cent ash. With increasing price and decreasing quality it will become more and more a luxury fuel to be enjoyed by those who care most for its smokelessness and relative cleanliness and foolproof qualities of combustion. It is an example of what will follow with our other fuels of very special qualities. In Virginia, Arkansas, and Colorado there are about 1.4 billion tons of coals of anthracite type, the most of which is not comparable in quality to the Pennsylvania deposit.

Between bituminous and anthracite coals lie some fifty-six billion tons of semi-bituminous coals. This is mostly in West Virginia, Pennsylvania, and Maryland in the East, and Oklahoma and Arkansas in the Middle West. In this group are our finest steam coals. We are drawing on these reserves at the rate of 65 million tons per year, shipping into regions that could be well served with local fuels of lesser future value. These must wait their turn to be appreciated when we have used up our best.

This subject of American Fuel Resources has been a matter of special study by the U. S. Geological Survey, whose publications, especially those by M. R. Campbell, should be consulted for a detailed treatment.

Factors Governing the Purchase of Coal

Leading Factors Entering into Coal Selection—Purchase on a Specification Basis—An Approved Coal-Contract Form—Suggestions for Study of Coal-Mining Districts and Individual Mines

By MORGAN B. SMITH,[1] DETROIT, MICH.

INDUSTRIAL steam generation is now emerging from that long primitive period in which steam-plant operation was merely operation and in which careful coal selection and purchase, beyond consideration of the delivered cost, was seldom seriously considered.

Industry, the country over, is awakening to the benefits to be gotten by proper coal selection, the greatest single factor involved in efficient steam-plant operation.

Significance of Plant Efficiency

In this country industrial steam plants at large show an average boiler and furnace efficiency of 56 per cent, whereas 70 per cent may reasonably be expected. Careful coal selection followed by comparatively inexpensive plant betterments and more intelligent plant operation will bring about this increase in efficiency.

In a plant burning, say, 100,000 tons of coal per year, a saving of 14 per cent in fuel will amount to 14,000 tons, which at $4 delivered price per ton, represents a saving of $56,000 per year. This is equivalent to $933,300 if capitalized at 6 per cent.

Purchasing Versus Plant Operation

Steam-plant efficiency can be raised only by coördinating (*a*) coal selection, (*b*) better plant operation, (*c*) betterment and proper maintenance of plant, (*d*) adequate records of plant performance, and (*e*) installation of instruments for the guidance of plant operators and for obtaining comparative operating data.

Thus it is apparent that coal selection and purchase cannot be divorced from plant operation unless plant efficiency is considered of little moment. Purchasing in general cannot be efficient without thorough coördination of its function with that of plant operation and management. Real team work among men of widely different training, experience, knowledge, and points of view must be attained before maximum efficiency can be gotten.

Purchasing agents are urged to line up their function in coal selection and purchase with that of the plant engineer and the boiler-plant operator.

How, then, shall we tie in these several functions?

COAL SELECTION

Coal selection is probably the most important single factor because only through proper selection can coal best suited to existing plant equipment be bought. Therefore let us consider the leading factors entering into coal selection.

1 The Boiler Plant

a Type and size of boilers.

b Volume and shape of combustion chamber.

c Firing methods, such as by hand, stokers, pulverized coal, wood refuse, coal and wood refuse, etc.

d Type of grates, stokers, pulverized-coal apparatus, etc.

e Average rating at which boilers are operated, including banking periods, and minimum and maximum ratings.

f Type of furnace construction, such as plain brickwork, air-cooled or water-cooled.

g Type of refractories used in furnace construction, especially with regard to resistance to fluxing and erosion; a matter of *maintenance cost* and also involving the question of continuity of plant operation.

2 The Coal

a General characteristics of the field or district and seam where the coal is mined should be determined, including analyses of *delivered* coal.

b The coal should be studied relative to its content of volatile combustible matter, ash, and sulphur. Considerable study should be made of the ash-sulphur ratio, as there seems to be a relationship (as yet undetermined) between this ratio and the fusing point of the coal ash.

c The burning characteristics should be determined at all usual ratings of boiler operation, to determine coking properties, clinkering tendency, etc.

d The three inerts in the coal structure—inherent moisture, ash, and sulphur—should be considered in order to determine the cost of true combustible content of the coal.

e Labor costs for conditioning of fires and for ash handling should be considered.

f Comparative costs of true combustible matter in several coals, including price at mines, freight, and handling charges, should be set up to determine which is the best coal relative to cost, always bearing in mind the plant equipment.

g Such coals may then be comparatively rated with respect to the amount of heat recoverable from each of them in the form of steam.

h By considering together the total delivered cost and the rating assigned to each coal we can determine a *base cost* for each coal, which logically may be the cost per 1,000,000 B.t.u. in each coal or may be the cost of 1000 lb. of steam in each ease.

i Such study should be followed by thorough service tests of several coals which have passed preliminary examination. Tests should be sufficiently exhaustive to determine what may reasonably be expected from each coal in regular plant operation covering all operating conditions.

j Comparative study and tests and gradual collection of coal data will eventually enable a purchasing agent to choose his coals for the particular steam-plant equipment with a high degree of accuracy, speed, and economy.

Eventually purchases will be limited to coals of certain well-defined characteristics obtainable in two or more districts, after which coal selection involves only the best market values conforming with the desired characteristics.

To make such a system workable we must systematically collect data on individual coals, which data then becomes capable of exact appraisal in advance of purchase.

We can then purchase a new coal with reasonable assurance regarding its behavior in any given plant.

k Too often coal buying is limited to one field or district. In time because of such limitation the buyer finds himself with but one source, accompanied by non-competitive prices and the chance that supply may fail in times of emergency. This all leads to limited experience with coals, whereas prudence indicates the value of broad experience with diversified sources, which comes only by trial of coals from different fields.

l Price relationship even among selected coals is in a constant state of change, and the ratio of price to test results soon becomes obsolete. The answer to such a condition lies in the installation and use of proper instruments in the boiler room so that the boiler plant will be in a state of daily test—the watchdog over coal selection and purchase, plant maintenance, and capital investment.

3 The Coal Mine

Each mine should be studied relative to its location, district, and seam, methods used for coal preparation, shipping facilities, shipping point, originating railroad and routing, freight rates, mine output, and coal reserves.

The labor question is very important. Is the mine unionized or not? What is the probability of mine shutdown?

Each selected or approved mine should be inspected at regular intervals, especially with regard to coal preparation. Is the preparation equipment adequate or not? Is it improved from time to

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For presentation at The First National Meeting of the A.S.M.E. Fuels Division, St. Louis, Mo., October 10 to 13, 1927.

time in step with changes in the coal seam, especially with regard to seam "partings?" Poorly prepared coal will contain more or less avoidable ash, which will involve higher freight and handling costs in terms of combustible matter shipped, as well as lower operating efficiency in the steam plant.

4 The Coal Vendor

The vendor, preferably a producer or sole sales agent, should be studied and rated with regard to his ability and intent, based on past performance, to deliver coal from specified mines as per contract or "spot" purchase agreement.

The vendor's financial stability should also be considered. Will he be in business one year hence or five years—or is he a "fly-by-night" operator working a mine merely to take advantage of a temporary demand? What has been his attitude toward his customers relative to productive wage increases at his mines? Has he made unjustifiable demands, or has he been reasonable in such matters? A coal buyer should always protect himself against such practices, remembering of course that productive-wage increases are often justified by conditions in the field. No buyer should pay more than the increase paid to true productive labor at the mine. Non-productive labor should not be considered.

5 Check on Quality of Coal Delivered

As a protection against receipt of coal poorer in quality than that specified in the purchase agreement, the buyer should insist that regular and representative samples be taken from the delivered coal for test purposes.

Shipping points should be checked on each car received; otherwise substitution of coal other than that specified may be made, especially if the vendor knows that such checks are not made. Nearly all producers and vendors have so-called "headliner" mines upon which they depend to sell their inferior coals. Constant checking of delivered coal for quality and shipping point is absolutely essential.

6 The Effect of Size of Coal on Price

It is a fairly general practice to sell $1^1/_8$-in. and $1^1/_4$-in. slack as 2-in. slack. The buyer should know that $1^1/_4$-in. slack as a rule contains approximately 25 per cent less fuel value than the 2-in. slack. The vendor figures that if he can cut from the 2-in. size to the $1^1/_4$-in. size he has added 15 cents per ton to his profit, which the purchaser of course pays.

7 Delivery in Cars Specified

Considerable expense can be saved by carefully specifying the type of car in which shipments shall be made. A plant equipped with track hoppers should specify Ralston hopper-bottom cars or their equivalent, whereas such cars are not suitable for delivery to a plant without track hoppers.

8 Routing and Scheduling of Coal Shipments

Proper routing and scheduling of coal shipments will save considerable handling expense. Each order for coal should contain definite routing instructions and a shipping schedule.

9 The Purchase Order or Contract

Too often an order for coal specifies tons only, whereas it should also state the mine from which shipments shall be made, the seam, the shipping point (name of same with county and state also named), routing, class of railway cars, etc. This may involve a little additional clerical expense, but when completed the buyer has a definite legal contract and he can refuse substitute coal if he so desires. Without such an order or contract the buyer has no legal redress under emergency conditions or on a rising market.

Confirmation of each order should be insisted upon by the purchaser, and such confirmation should be carefully checked against the original order as soon as the confirmation is received. It is an acknowledgment by the vendor that he not only understands the contents of the order but also accepts it in its entirety. If the vendor's confirmation and your order agree, or are made to agree if necessary, you will not have to call in your legal department to straighten things out.

10 Price Agreements

Orders should be placed at a definite price, especially in the case of "spot" orders. Contracts may be made, and often are, on a sliding scale of price. In either case the order or contract should contain a clause under which no increase or decrease in price can be made during the life of the order or contract unless the purchaser is given at least ten days' written notice prior to such price change, and only after receipt by the vendor of purchaser's written acceptance of such price change, and furthermore, the purchaser should have the right within the ten days to cancel the order or to transfer the unshipped tonnage to another approved mine located in a district wherein such price changes have not been found necessary. The clause should also make it obligatory that the vendor shall notify the purchaser of any price reductions so that the purchaser may benefit thereby. This all refers to necessary increases in productive-wage scales, often reflected in the price of coal by demands on the part of the vendor that the purchaser pay the contract or order price plus the productive-wage increase. Obviously the buyer should determine the justifiable increase in price.

11 Checking Car Shipments

Mention has been made of the need for checking shipping points, the only protection the purchaser has against substitution of inferior coal for that covered by the order or contract.

A system which is simple and works well may be outlined as follows:

a Original requisition is filed with a copy of the purchase order.

b Freight bills received are forwarded to the man in charge of unloading the coal. After he has inspected and unloaded the coal and is satisfied that the shipment is O. K., he forwards receipted freight bills to the filing room.

c In the filing room the freight bills are placed with the order and requisition.

d Upon receipt of the vendor's invoice the comptroller calls for the complete file, and checks the invoice against the records to establish the shipping point and mine against those specified.

12 Coördination of the Purchasing Function and the Power-Plant Operating Function

The points of view of these two functions, each of which in its way may be correct, are often widely different and too often irreconcilable.

For example, the purchasing department, with the consent of the management, may yield to the insistence of the operating staff, upon the purchase of a certain coal, which as a matter of fact can be duplicated in every essential respect, at a lower price. On the other hand, the reverse may be true, and a management with a prejudice for low unit cost of material supports the purchasing department in the selection of low-priced coal of such a character that resulting operating losses more than offset any apparent but unreal gains made in buying. These two extremes must be brought together in such a way that the coal buyer will see and understand the viewpoint of the plant operator; that the latter shall appreciate the purchasing department's problem of coal selection and purchase; that the management will understand why the plant operator has asked for plant betterment, etc. The joint success of such procedure has much to do with plant management, not the least of whose problems consists in keeping capital investment within bounds.

13 Approved Coal Mines and Vendors

In one form or another, every coal buyer should develop a list of approved coal mines and vendors. The number of mines will depend on the coal tonnage involved, but in any event they should provide diversity of sources, i.e., districts and seams. Such a list should be kept up to date and alive. It may in time consist of (*a*) several "permanent" or proved sources, (*b*) a few doubtful sources more or less subject to rejection, and (*c*) of a few new sources on trial for say one year or longer if advisable. Sources under (*a*) are retained subject to good behavior; those under (*b*) are likely to be dropped unless markedly improved behavior is shown during a period of one additional year on the list; those under (*c*) are under close observation and their behavior will determine whether they will advance in rating or be dropped.

There is little to be gained by continually switching around from

vendor to vendor or from mine to mine, but the purchasing agent should switch around until he has been able to develop several dependable sources to assure continuity of supply and competitive purchasing.

Purchasing agents should cultivate their coal sources; should give courteous reception to the sellers sent out by such sources. Hearings of this sort are as a rule mutually advantageous.

14 Classification of Coals

There is a movement on foot whereby coals are to be "classified," and such a movement is one in the right direction. Let us all hope that it does not stop with a mere geologic grouping of coals, but goes farther and tells us what the burning characteristics are; what the behavior of coals will be under conditions of high rates of combustion, etc. In other words, the purchasing agent and the plant operator need competent and unbiased advice as to which coals will suit their plant equipment, and they do not much care on the face of it whether a coal belongs to this or to that geologic age.

Furthermore, while this "classification" work is under way, we believe that those doing this thing might well take the time to gather together the scattered data on coals, preferably in handbook form, for the ready use of those purchasing or burning coals.

15 Purchase of Coal on a Specification Basis

A specification covering the purchase of coal to be a success must be workable; and to be workable it must be equitable; and unless it is equitable it will not hold as a legal contract.

A bonus and penalty clause in the case of industries will work well provided that penalties do not overtop bonuses. The value of such clauses is open to serious doubt. In almost every instance which has come to the author's attention they result in ill will between the parties to the contract. There are no doubt exceptions. In the long run, coal of reasonably uniform quality can be purchased without such clauses at prices which offset any gain to be made through bonus and penalty provisos in the contract.

a A large automobile plant buys its coal on a simple specification containing a bonus and penalty proviso. In this case buying has been "successful." It is admitted that bonuses and penalties are practically in balance all the time, and both parties to the contract are happy. Briefly, this specification reads as follows:

The coal shall be a good grade of mine-run coal free from bone, slate, dirt, and excessive dust, and of such a nature that when crushed, it will flow freely. It shall not take fire spontaneously while stored. The chemical and physical properties of the coal, when determined on the basis of an air-dried sample, shall be:

	Minimum	Maximum
Moisture, per cent	0	2
Volatile matter, per cent	30	37
Fixed carbon, per cent	55	60
Ash, per cent	6	8
Sulphur, per cent	—	2.0
B.t.u. per lb.	13,500	14,500
Fusing point of ash not less than	2700 deg. fahr.	
Ratio of volatile to fixed carbon	0.50	0.65

Payment for coal will be made upon the basis of the agreed price, corrected for variations from the specified standards in heating value and ash contents.

When the variation in B.t.u. exceeds or is below the specified amounts, the correction in price will be a proportional one.

Premiums on ash content will be as follows:

Ash content, per cent	Per cent premiums, f.o.b. destination, on purchase price
5.00–5.99	1
4.00–4.99	2
3.00–4.00	3

Penalties on ash content will be as follows:

Ash content per cent	Per cent reductions, f.o.b. destination, in purchase price
8.01–9.00	1
9.01–10.00	2
10.01–10.50	4
10.51–11.00	8
11.01 or over	Special adjustment

When price adjustments for both B.t.u. and ash content are necessary, that due to B.t.u. variation shall first be determined and that due to ash variation shall be figured on the price as revised for B.t.u. content.

b Another automobile manufacturer buys his coal satisfactorily on the following specification, without a bonus or penalty proviso.

	Mine run	Nut and slack
Inherent moisture, max., per cent	1.5	1.5
Volatile matter, max., per cent	35.0	35.0
Fixed carbon, per cent	56.5	56.5
Ash, max., per cent	7.0	7.0
Sulphur, max., per cent	1.0	1.2
Oxygen, per cent	8.0	8.0
B.t.u. per lb. as received	13,900	13,750
Softening point of ash, min., deg. fahr.	2,750	2,600

c A very large plant limits its specification to a careful statement regarding preparation of coal because they know that the coals on their approved list are satisfactory in every way *if properly prepared*. This statement is as follows: "Coal furnished shall be prepared in such a manner that material foreign to coal, *in*, *above*, or *below* the seams, shall be eliminated as far as possible. Coal specified shall not contain more than 8 per cent of ash. If the ash content exceeds 8 per cent the buyer may refuse to accept the coal in question." This simple specification is still working well after approximately 15 years' duration.

16 Coal-Contract Form

The ordinary material-purchase form is seldom suitable for writing coal contracts. A form which works well is as follows:

STANDARD NUT, PEA AND SLACK, AND MINE-RUN COAL CONTRACT

(Name of Purchaser) .....

Agreement entered into this ..... day of ..... 19.... between .....

.....

hereinafter referred to as the "Seller" and .....

.....

hereinafter referred to as the "Buyer," *Witnesseth:*

The Seller agrees to sell and the Buyer agrees to purchase, at the price agreed upon subject to the following terms and conditions, *Coal*, hereinafter referred to as the "Article."

Specified Sources and Description

	Mine	Seam	Shipping Point — Town	County	State
1.					
2.					
3.					
4.					

Quantity and Size—Net Tons of 2000 Lb. ..... Size .....

Weight of Shipments—

Railroad weights shall govern tonnage shipped, excepting that if later such weights are found to be incorrect by the Railroad and by the Buyer, then such corrected weights shall apply.

Price for Net Ton of 2000 Lb., F.O.B. Mine ..... $.....

Terms of Payment .....

Destination and Routing .....

.....

Schedule of Shipment—Delivery shall be made between the date hereof and ..... as may be specified from time to time on Buyer's regular Purchase Order, and in accordance with the requirements of Common Carriers. Shipments will be made *where directed by Buyer* in the case of embargoes on shipments to point of delivery herein specified.

Railroad Cars Desired .....

Preparation of Coal. (As in Specification *c*, Par. 15 above)

Specification. May or may not be included as desired by Buyer.

Seller's Performance. If production at specified mines falls below the amount herein specified the Seller shall ship whatever coal is produced. This shall not, however, authorize the Seller to ship less than the specified amount where production equals or exceeds the amount herein specified.

[This is a somewhat drastic clause but is workable and in force in several instances. If this clause is found too drastic, terms and conditions of the "Standard Coal Contract, Form A or B," recommended by the National Association of Purchasing Agents, may be used. Many coal vendors provide their own contract forms which always include a vendor's performance clause, generally designed solely for the vendor's protection.]

Non-Performance Excused. The Seller shall not be responsible for delays or defaults in deliveries nor the Buyer for failure to receive, if occasioned by wars, strikes, fires, the act of God or the public enemy, labor or transportation difficulties or other causes beyond their control.

Seller's Wage Scales. The price herein specified is governed by the Seller's productive-wage scales in force at the time this contract goes into force, namely, Seller's base day-wage scale is $..... Seller's hourly wage scale is $..... for productive labor. Increase in price over that herein specified shall take effect only upon Seller's written notice to the Buyer at least ten days prior to such increase and upon Buyer's acceptance of same.

Increase in price shall not be effective until shipments shall have been completed which were specified before such written notice is sent to the Buyer by the vendor.

The Buyer will not consider any increase in price over that specified in this contract unless such productive-wage increases are general in the district wherein the specified mine or mines are located.

In the event of such increase, the Buyer may cancel this contract or shall have the right to accept unshipped tonnage covered by this contract from a mine or mines, as agreed upon between Seller and Buyer, at which productive wage increase have not been made. The Buyer shall receive the benefit of any and all subsequent reductions in productive wage scales and the Seller shall at once notify the Buyer of any and all such reductions upon their consummation.

The Buyer shall have access to Seller's books in case of dispute in order to determine the amount of increase per ton justified by Seller's increase in the cost of productive labor.

Insolvency and Cancellation. (The usual legal form.)

Remedies, Etc. (The usual legal form.)

Privacy of Contract. (The usual legal form.)

Non-Assignment of Contract. (The usual legal form.)

IN WITNESS WHEREOF the parties hereto have executed these presents in duplicate the year and date first above written.

..... Seller ..... Buyer

By..... By.....

OUTLINE SPECIFICATION OF COAL

PARTIES TO CONTRACT: Seller; Purchaser

General and Specific Clauses:

- Producer's or seller's bond—Surety Co.
- Coal to be furnished: Trade name; Region mined—state mines, seams; shipping point—town, county, and state; Size limits, if any; Quantity (Max.): Per cent allowed for varying requirements—pro rata tonnage in case of strikes; Reserve for test purposes—right to buy no open market—per cent of max. quantity
- Purchaser's Option: Rights in case of seller's failure to fulfil contract—annulment of contract clause
- Shipments: Notice to seller as to requirements; Delivery: When—period; Where—tracks at yards; How—types of cars desired; Routing; Weights: Railway bills expense to purchaser; Purchaser's weights
- Payments: Price: Mines—productive-wage changes; Freight—changes in rates—how adjusted; When to be made—monthly or otherwise
- Basis-quality: Specification—Bonus and penalty clause—Scale of price per ton: Sizing; B.t.u. dry coal; Per cent ash and fusing point; Volatile; Fixed carbon; Sulphur; Nitrogen; Inspection clause
- Tests for Quality: Made by whom; Test to be made: When; Where; by whom—seller—purchaser—referee; Methods to be followed: Sampling; Analysis; Test reports: Forms; Sent to whom

17 SUGGESTIONS FOR STUDY OF COAL-MINING DISTRICTS AND INDIVIDUAL MINES

a Determine the relationship between ash and B.t.u. content.

b Determine, eventually, the effect of sulphur upon the softening point of coal ash (if such a relationship exists).

c Check up the preparation at the mine of coal delivered to your plant by watching the variation in ash content.

d Check up with your plant engineer the performance of purchased coal in your steam plant. He is in a position to assist you in your problem of coal selection.

e Study your vendors relative to their performance on contracts and on "spot" orders. Study their attitude toward you, one of the outlets for their product. Study their general business policy. In time you will develop a list of thoroughly dependable sources.

f Develop a diversified list of sources to protect yourself against emergency conditions. Study routing of shipments as well as freight rates.

Much of the foregoing may seem to relate more to the steam plant and the chemical laboratory than to purchasing, and, frankly, it is the author's intent to show that the purchasing function cannot operate effectively unless it ties in with steam-plant operation. And steam-plant operation cannot be most highly efficient unless the plant operator ties in with the purchasing function in the selection of proper coal.

Mechanization Survey of Coal Mines

THE present investigation into the possibilities of mechanical mining was begun early in 1927 by G. B. Southward, the author of the present report, under the auspices of the American Mining Congress. Four of these reports (Nos. 111, 418, 610, and 623) submitted show the successful application of conveyors to room and pillar mining. In these operations the haulage entries are developed by hand loading into mine cars, and the conveyors are restricted to room advancement and pillar recovery.

The four units covered by the reports all represent successful operation. In some cases additional equipment has already been installed. The survey, which includes thirty operations showing mechanical loaders, scrapers, conveyors in room and pillar, longwall, and modified systems, shows a sufficient number of successful operations, methods, and equipment to conform to physical conditions, and to raise the question as to whether the old hand methods can expect to compete against mechanized mining and can survive in the face of an increased mechanized production.

In each of these mines the conveyors used are a low type, and it is obvious that a miner can shovel a greater tonnage on to these conveyors than he can into mine cars. However, other work is required as part of the loading operation, such as moving the face conveyor forward, extending haulage conveyors, timbering, drilling, and shooting. In each of the reports submitted the number of men regularly employed to perform these operations is shown under the paragraph "Operating Crew," and the amount of work done in each shift is described with the average tonnage produced. The most conclusive manner of determining whether or not these operations are being performed more economically than by loading into mine cars would be to show a comparison of the mining costs. But mining costs are confidential, and figures of this nature cannot be published. However, from these reports the average tonnage and the men employed for the conveyor operations—from the face to the gathering side track—is shown for both high and low coal, and a comparison can be approximated with the labor which, under ordinary and similar conditions, would be required for the same operations and for the same tonnage in hand loading with mine cars. (G. B. Southward in *The Mining Congress Journal*, vol. 13, no. 8, August, 1927, pp. 598–602, 4 figs., *g*.)

The Measurement of Atmospheric Pollution, Visible and Invisible

By GEORGE T. MOORE,[1] ST. LOUIS, MO.

WHILE the ultimate solution of the problem of how cities are to acquire a smokeless atmosphere must depend upon the coöperation of the mechanical engineer with the fuel specialist, it is highly important that during the preliminary stages of any investigation, as accurate an idea as possible be obtained of the amount of pollution either normally or abnormally present in the air.

Until comparatively recently all efforts to determine the amount of pollution in the atmosphere have been confined to measuring more or less crudely the amount of solid matter in the air, no attention whatsoever being paid to the gases or acids which may be formed through the incomplete combustion of coal. Even at the present day one of the standard methods is the so-called "soot-fall" study, in which the soot is collected in suitable containers and after being filtered and weighed is heated to ignition, and the loss in weight, which represents the combustible material, is reported as soot. This weight of soot is calculated in tons per square mile per annum, and by this means figures are obtained which can be compared with the results secured at different localities in the same city or in different cities. Obviously such a method is subject to a high percentage of error and can only measure the soot that is heavy enough to be deposited by its own weight from the air. Crude as this method is, it does give a certain basis for estimating the amount of solid matter in the air, and it is customary in any smoke survey to resort to it if for no other reason than to be able to note any improvement which may occur from year to year. But the objections to the "soot-fall" way of determining anything like the total amount of atmospheric pollution are obvious.

The Owens Automatic Air Filter

Thanks to the activities of the Advisory Committee on Atmospheric Pollution in Great Britain, there has been devised a much more satisfactory means of obtaining accurate information concerning the amount of solids in the air. A notable achievement is an instrument for determining the amount of solid impurity in the air at any time by drawing a measured volume of air through a small circular area of filter paper. This machine was designed and constructed by the Honorable Secretary of the Committee, Dr. J. S. Owens, and is now commonly known as the Owens automatic air filter. It takes about ten minutes to complete the filtration of one charge of air, which is exactly two liters. The instrument renews automatically the quantity of air to be filtered, and a new circle is exposed on the filter paper as soon as one charge is disposed of. Thus from four to five samples of air per hour can be analyzed and a permanent record of impurities obtained for every fifteen or twenty minutes throughout the twenty-four hours for an entire year or longer. The advantage of being able to definitely compare conditions which occur at the same day and hour a year previous, or at any other desired time, is of great value in any smoke survey.

By means of a carefully prepared color scale the individual records made by the air filter can be matched up, and a fairly accurate idea obtained of the amount (in milligrams) of suspended matter contained in two liters of air.

One rather surprising result from the use of the Owens air filter was to demonstrate that doors and windows do nothing to keep out the finely divided particles that are carried by the air. At first it was naturally supposed that in order to get a proper sample the machine would have to be set up out of doors, but experience has shown that air in a closed room is just as dirty as that out of doors.

The Jet Dust Counter

Still another method of measuring air pollution which has the advantage of being portable is by means of the so-called "jet dust counter," also devised by Dr. Owens. This method depends upon the well-known fact that when air containing finely suspended particles and a sufficient amount of water vapor has its pressure suddenly reduced, there is a fall of temperature and moisture condenses on the dust. If these moisture-covered particles come in contact with a glass surface, the moisture evaporates and the dust particles adhere to the glass and can be counted.

The jet-dust-counter apparatus consists of a tube or chamber lined with blotting paper which is wet with water. A small air pump of known capacity per stroke is attached at right angles to the bottom of the tube. This end of the tube is blocked by a metal plate containing a narrow slit and is arranged so that a clean cover glass just fits, and when the pump is operated the particles contained in a given volume of air are deposited upon the cover glass where they adhere and can then be examined and counted under the microscope.

Measurement of Acidity of the Air

It has long been recognized that carbon alone is not the cause of all the damage produced by smoke. In regions where large quantities of bituminous coal are burned there is certain to be a considerable amount of sulphur volatilized, and this readily oxidizes to sulphurous and sulphuric acid. Much of the destructive action from excessive amounts of smoke is due to these as well as certain other organic acids. While it is true that the finely divided carbon acts as a carrier for the volatilized sulphur and the quantity of carbon in the air is a general indication of the possible amount of destructive acids present, this in no way furnishes an accurate measure of the acidity of the air, and other means must be used for determining this. Dr. Owens and others connected with the Committee on Atmospheric Pollution of the Meteorological Office of Great Britain have been the pioneers in this work. At first experiments were made with a special tintometer for the estimation of acid by the use of an absorption tube containing the indicator solution. Ultimately, however, an apparatus was devised depending on electrical conductivity combined with electrical dust precipitation, and this at the present time constitutes one of the most accurate and satisfactory means of determining the quantity of acid present at any given time in the air. Briefly, this apparatus consists of a small covered silica dish in which a few cubic centimeters of conductivity water are placed. The dish has inlet and outlet tubes, and a wire passing through the cover makes contact with the water. Air is drawn through a space above the water, and by regulating the rate it deposits all its dust in the water. The water is then heated and its conductivity measured by means of a special form of electrode. The sensitiveness of this apparatus is almost unbelievable. For example, a small piece of soot accidentally falling into the water altered the resistance from 7800 ohms to 2700 ohms, and this in a few seconds. Simply touching the surface of the water with the finger for an instant will sometimes reduce the response as much as one-half. In addition to precipitating suspended matter, the apparatus has proved to be effective for determining gaseous acids.

Apparently the best method yet devised for determining the amount of sulphur dioxide in the air is the starch-iodine method described in the report of the Selby Smelter Commission, Bureau of Mines Bulletin 98, Department of the Interior. Certain modifications of the method of sampling devised by the Department of Agricultural Research, American Smelting and Refining Company, have greatly increased the delicacy of the test, since much larger samples of air can be taken. It is the author's understanding that the American Smelting and Refining Company is now able to take continuous samples of air, each of two minutes' duration, or by aspirating through one solution indefinitely it is possible to draw as many liters of air through the apparatus as desired,

[1] Director of Missouri Botanical Garden.

For presentation at the First National Meeting of the A.S.M.E. Fuels Division, St. Louis, Mo., October 10 to 13, 1927. Slightly abridged.

thereby making it possible to determine sulphur dioxide in one part in one hundred million if necessary.

DETECTING THE PRESENCE OF PATHOGENIC ORGANISMS IN AIR

While not directly connected with the smoke problem, the question of the number and kind of disease germs which may be present in city air is of course an important aspect of atmospheric pollution. Bacteriological and sanitary engineers have called attention to the possibility of polluting air by the scattering of fine particles of mucous and saliva in coughing, loud speaking, and sneezing. There seems to be no question that pathogenic organisms from infected persons enter the air and may by this means be subsequently transmitted to other individuals. Actual experiments in closed rooms show that harmless bacteria introduced into the mouth can be recovered after a half-hour of loud speaking at a distance of forty feet in front of and twelve feet behind the speaker.

Some years ago Mr. Nolte, working in the laboratories at the Missouri Botanical Garden, succeeded in identifying the most characteristic salivary organism and in devising means of isolating it from the air. A glass tube containing a layer of very fine sand was connected with the rubber bulb in such a manner that when pressure was applied and a pinchcock opened the air contained in the bulb was expelled through an exhaust without disturbing the sand in the filter. Upon releasing the pinchcock and afterward the bulb, 300 cu. cm. of air was drawn through the sand at each operation of the bulb. The whole apparatus was inconspicuous and when wrapped in paper attracted no attention, so that samples of air could be taken in street cars, public buildings, etc., without attracting attention. After returning to the laboratory the sand from the filter was poured into a flask containing sterile distilled water and the contents thoroughly shaken. Aliquot portions were plated on nutrient agar, and after incubation the number of colonies and nature of the organism could be determined. Thus as a result of this work the presence in the air of the most characteristic salivary organism can be determined, and this be used as an index of the possible presence of pathogenic organisms in precisely the same way that *Bacillus coli* is used as an indication of the possibility of the presence of disease germs from sewage in drinking water.

While progress is slow and the whole problem of smoke abatement is necessarily complicated by various economic considerations, the fact remains that public opinion is gradually being aroused. Cities in this country are before long going to insist that all unnecessary and preventable pollution of the atmosphere be eliminated, just as they now demand that the domestic water supply be protected. Any and every method which can be devised to measure the amount of harmful matter in the air should be resorted to, since it is only from information acquired in this way that the proper remedies may be applied.

Lubricating Power Cylinders of Diesel Engines

Report of Tests Conducted to Show Ill Effects of Oxidation

BY W. O. NORTHCUTT,[1] TULSA, OKLA.

IT IS the purpose of this paper to offer constructive criticism of the present methods of applying lubricating oil to power cylinders of Diesel engines, and to recommend a method which is believed to be an improvement. The discussion, the data, and the conclusions of this paper are based on an experimental study of this phase of Diesel-engine lubrication.

Regardless of the base of crude oil from which lubricating oils may be made, oxidation takes place after a certain temperature is reached. This is first noticed in the darkness of color, oxidation forming in the oils undesirable molecules of asphaltenes, the extreme of which is artificial asphalt, a black, sticky matter which has a very high coefficient of friction in comparison with that of the original oil. This oxidation takes place regardless of what care or methods are used in refining these oils.

Lubrication is gradually being considered as a separate study in the design of Diesel engines, and in some cases advancement has only been obtained by the coöperation of the customer with the Diesel-engine manufacturers. If an improper method is used for application of lubricating oils to the power cylinder, the oxidation of the oil is greatly increased, forming undesirable products in the new oil before it reaches the pistons. These undesirable products formed by oxidation increase friction rather than reduce it, which results in a high cylinder-liner and piston-ring wear.

With normal conditions, properly designed cylinder liners, and piston rings made of the proper material, and using a partially perfected method of applying lubricating oil to the pistons, it is possible to operate 750 to 1000 hr. per 0.001 in. of cylinder-liner wear. With these same conditions and a proper method of applying the oil to the pistons, one may expect to obtain from 1800 to 2000 hr. per 0.001 in. of cylinder-liner wear at the maximum cylinder diameter. The arrangement of the lubricating-oil piping, the lubricating-oil injection tube in cylinders, the size of lubricating-oil ports in the cylinder liner, and the design of the mechanical lubricator and the lubricating-oil injection tube are the necessary details to be considered in the control of oxidation of the oil.

Some of the details of cylinder lubrication which assist in the oxidation of the oil are large oil ports in the cylinder lines, air pockets in the lubricating-oil injection tubes, air pockets in the lubricating lines between the mechanical lubricator and cylinder check valves, and oil grooves arranged in piston skirts of the pistons or around the inner circumference of the cylinder liner. Take for an illustration a certain lubricating-oil injection tube containing a check valve located near the end of a tube which is secured in the cylinder liner. From the end of the injection tube leading into the interior of the cylinder liner there is a large oil port $^{11}/_{16}$ in. in diameter, forming a pocket approximately $^{5}/_{8}$ in. deep. The oil port is located between the fifth and sixth piston rings when the piston is on bottom center. At this time the oil should enter the cylinder past the check valve; but this is not the case and it would appear that on the downward stroke of piston the gas pressure behind the bottom or lower piston ring whips out on to the piston skirt the oil that might have passed the check valve or accumulated in the oil port. The piston is not water-cooled and the oil accumulates in a series of oil grooves around it, so that the oil is gradually decomposed by heat into an asphaltic matter, and later is transferred to the cylinder walls with its lubricating properties destroyed. Under the above conditions the base from which the oil is refined may play an important part. The hydrocarbon molecules of the paraffin crudes belong to the family known as the open chain, the carbon atoms being fully engaged and tetravalent, and each carbon atom is attached to four other atoms. The hydrocarbon molecules of lubricating oil refined from the asphalt crudes are capable of absorbing hydrogen, oxygen, or sulphur, which may be the constituents of the gases behind the piston rings. If the lubricating systems were so arranged as to have new, clean oil at the inner portion of the cylinder liner for the piston rings to wipe over and spread into a film on the liner walls, then the base of the crude from which the lubricating oil is refined would not be the controlling factor. The viscosity of the oil would be the controlling factor.

A special lubricating-oil injection tube, shown in Fig. 1, has been designed and has been used for over a year. The function of the tube is to deliver the oil in an unoxidized condition at the inner portion of the cylinder liner at a point between the first and second rings from the top of the piston when the piston is on bottom center, which assists the piston rings to spread the oil in a film on the walls of the cylinder liner. The injection tube contains a small

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[1] Sinclair Pipeline Company.

Contributed by the Petroleum Division and presented at the Kansas City Meeting, Kansas City, Mo., April 4 to 6, 1927, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

ball check valve, and has a small plug pressed into it at the cylinder end. This plug has a small spiral groove cut around it. One end of the plug terminates at the inner portion of the cylinder liner, and the function of the spiral groove is to prevent the oil from being whipped out on to the piston skirt as the rings pass over the port. This keeps the oil at the proper place at the inner portion of the cylinder liner, from which the piston rings pick it up and spread it over the walls of the cylinders in a clean, unoxidized form.

More attention should be paid to the condition of the oil film than to the quantity. The pulling of pistons and the finding of the cylinder walls well covered with an oil film is often misleading, because the oil may contain oxidized products that are detrimental to lubrication.

From the data of an experimental study on the condition of the lubricating oil in the lines of a system illustrated in Figs. 2 and 3, the analyses for the new oil and for the same oil taken from the injection tubes and branch feeding lines are given in Tables 1 to 5. The cylinder has two lubricating-oil feed lines from the mechanical lubricator to the check valves, one at the front and one at the back of the cylinder. From each check valve the lines branch, leading to one lower and two upper injection tubes as shown

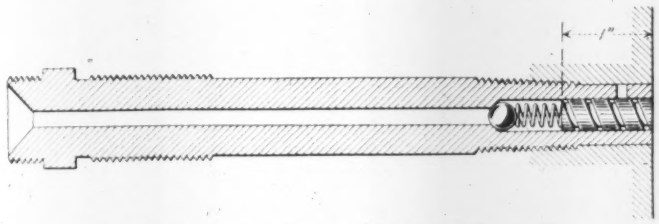

FIG. 1 LUBRICATING-OIL INJECTION TUBE

in Fig. 2. Due to the smaller resistance, the lower injection tube gets the larger portion of the oil. As the branch feed lines and lubricating-oil injection tubes contain air pockets, these branch lines are only partly filled with oil and this is oxidized by the cylinder gases, resulting in an irregular supply of oil at the inner portion of the liner. This irregular supply is made more irregular because a lubricator pumps air which accumulates in the highest part of the feed lines between the mechanical lubricator and check valve, especially if the lubricator is located above the cylinder check valve so that the oil may be fed downward.

The original characteristics of four used oils in the tests are given in Table No. 1.

TABLE 1 CHARACTERISTICS OF NEW OILS

Oil No.	Flash, deg. fahr.	Fire, deg. fahr.	Viscosity at 100 deg. fahr., Saybolt univ., sec.	Viscosity at 210 deg. fahr., Saybolt univ., sec.
1	410	460	410	59
2	410	470	398	55
3	425	490	555	65
4	455	520	1030	85

The analysis of a sample of oil No. 2, taken out of branch feed lines of cylinders after the engine had run for a year, is given in Table 2.

TABLE 2 ANALYSIS OF OIL NO. 2 TAKEN FROM BRANCH FEED LINE TO CYLINDER

Viscosity Saybolt universal at 100 deg. fahr., sec.		480
Water, per cent		1.38
Total sediment, per cent		1.78
Analysis of total sediment:		
Asphaltic matter, per cent	0.73	
Carbonaceous matter, per cent	0.94	
Ash, per cent	0.11	

The oil was very black in color, and the analysis shows the true condition of the oil to which it is converted before reaching the pistons.

The analysis in Table 3 is for oil sample No. 1 taken out of the branch feed lines after the lines had been cleaned out and the engine run for two weeks.

TABLE 3 ANALYSIS OF OIL NO. 1 TAKEN FROM BRANCH FEED LINE TO CYLINDER, END OF TWO WEEKS' RUN

Flash, deg. fahr.		405
Fire, deg. fahr.		465
Viscosity, Saybolt universal at 100 deg. fahr. sec.		466
Viscosity, Saybolt universal at 210 deg. fahr., sec		60
Acidity No.		0.226
Total sediment, per cent		0.42
Analysis of total sediment:		
Asphaltic matter, per cent	0.140	
Carbonaceous matter, per cent	0.218	
Ash, per cent	0.062	

The analysis in Table 4 is for oil sample No. 1 taken out of the branch feed lines after the lines had been cleaned out as before and when the engine had run for four weeks.

TABLE 4 ANALYSIS OF OIL NO. 1 TAKEN FROM BRANCH FEED LINE TO CYLINDER, END OF FOUR WEEKS' RUN

Flash, deg. fahr.		410
Fire, deg. fahr		470
Viscosity, Saybolt universal at 100 deg. fahr., sec		482
Viscosity, Saybolt universal at 210 deg. fahr., sec		62
Acidity No		0.0560
Total sediment, per cent		0.74
Analysis of total sediment:		
Asphaltic matter, per cent	0.300	
Carbonaceous matter, per cent	0.365	
Ash, per cent	0.075	

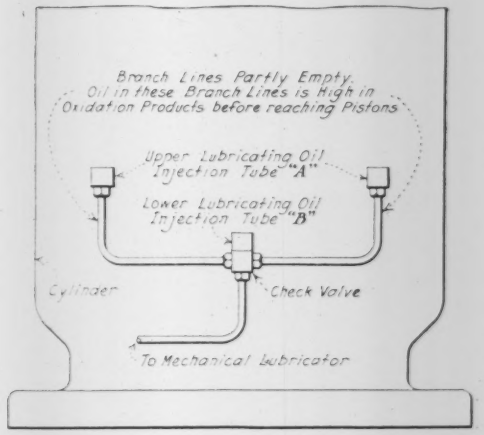

FIG. 2 LUBRICATING-OIL SYSTEM

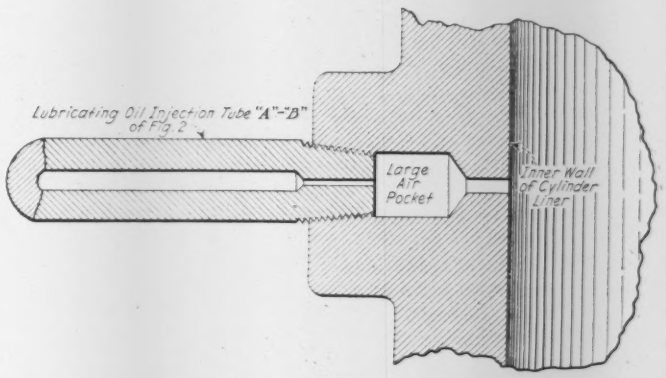

FIG. 3 LUBRICATING-OIL INJECTION TUBE OF SYSTEM SHOWN IN FIG. 2

Table 5 gives analyses for samples of oil Nos. 1, 2, 3, and 4. These samples were taken out of branch feed lines after the lines had been cleaned and engines had been running 48 hours. These analyses are for the total sediment only.

The analyses of Table 5 show the true condition of the oils as they reach the interior of the cylinder liner. The figures in Tables 1 to 5 show conclusively an increasing degree of oxidation with the number of hours. In all of these tests the engine was run under similar operating conditions. These detrimental conditions of lubrication can be overcome by proper attention to the design of the lubrication system. Pistons of two-cycle engines can be successfully lubricated above the exhaust ports by using a properly designed lubricating-oil injection tube, a properly designed lubricator which pumps oil only, and individual pumping units that can be timed separately in relation to the piston.

To lubricate a two-cycle engine below the exhaust ports, the oil port should be very small and should be located under the center line of the bridge.

In engines which rely mainly on a splash system for lubricating the power cylinder, thereby doing away with the mechanical lubricator, oxidation of the oils is unavoidable, and therefore the oil contains undesirable products. The author has not had an opportunity to investigate the efficiency of this method.

In conclusion the author believes that the use of an improved lub-

TABLE 5. SEDIMENT ANALYSES OF OILS NOS. 1, 2, 3, AND 4 AFTER 48 HOURS' RUN

		Per cent
Oil No. 1:	Asphaltic matter	0.034
	Carbonaceous matter	0.080
	Ash	0.021
	Total	0.135
Oil No. 2:	Asphaltic matter	0.049
	Carbonaceous matter	0.164
	Ash	0.034
	Total	0.248
Oil No. 3:	Asphaltic matter	0.055
	Carbonaceous matter	0.084
	Ash	0.016
	Total	0.154
Oil No. 4:	Asphaltic matter	0.073
	Carbonaceous matter	0.182
	Ash	0.060
	Total	0.315

ricating system for power cylinders of Diesel engines such as that outlined in this paper will provide a means of applying the lubricating oil to the cylinder liners without destruction of its lubricating quality by oxidation from cylinder gases. He further believes that such a method will effect not only the proper method of lubrication but also a saving in lubricating oil and a materially reduced cylinder-liner wear, regardless of the base of crude oil from which the lubricant is refined.

Discussion

J. H. GALLOWAY,[2] referring to the difficulties of lubricating a Diesel-engine cylinder by means of a splash system, said that it had been found experimentally and in practice that Diesel-engine cylinders up to twenty-two inches in diameter might be lubricated satisfactorily by that system, with a clearance between the piston and liner of only 0.014 in. The data that had so far been secured on the performance of a cylinder of that size showed that when using that system of lubrication the wear was no greater than when a force-feed system was used with the type of check valve shown by the author.

He believed that very few engine builders had paid much attention to the subject of lubricating a Diesel-engine cylinder. In the last few years, however, more attention had been paid to it, especially to the operating problems, and to the design of piston rings. The design of the piston ring of a Diesel engine had a great effect on liner wear, because the pressure on the tops of the first two or three rings forced them down against the bottom of the ring land, leaving a clearance between the top of the ring and the top of the ring groove. The gas back of the ring forced it out against the cylinder wall, and the tension on the spring plus the gas pressure behind the ring determined largely the amount of wear.

S. A. Hadley[3] agreed with the author that oil should not be exposed to the air before being admitted to the surface of the cylinder.

He did not believe that there was a tendency to force gas into the port cavity, because he had applied pressure gages and had found no such pressure to exist as the rings prevented it.

It seemed to him that the author was wrong in trying to introduce the oil above the rings where the outlet would be subjected to high pressure; it might be better to put it below.

Cylinder-ring wear varied so much with different conditions, he said, that any general statements should be made with caution. Temperature had a great effect on the wear. A Diesel-engine cylinder wore in two places, at the top where the ring pressure was greatest, and at the bottom where the skirt would wear only if there were uncertain lubrication. It might cease due to lack of oil, but there would be no permanent harm. The wear which made it necessary to discard rings and liners came from the grit in the oil caused by ash in the fuel and charred, unconsumed fuel, or by charred lubricating oil. The problem was to keep excess oil from the ring travel—to allow as little as possible to come into the path of the ring.

F. I. Kemp[3] said that in making tests of any sort on cylinder-liner wear, the matter of temperature was very important. The mean effective pressure of an engine was also important because it determined the loading of the engine or the amount of fuel burned in that particular cylinder resulting in heat. There was also the question of proper cooling of the engine. Some engines were better cooled than others, due in some cases to the cooling system, in some cases to the engine design, and in other cases to the kind of water used.

He knew of one cylinder lining which was reported to have worn 0.25 in. in about eighteen months. There was no trouble with the lubricating oil, so far as could be told, but the cylinder walls were thickly caked with scale, so the cylinders were running with very little cooling effect.

He knew of another engine in which, after three years of practically continuous service, the average wear in six cylinders 22.5 in. in diameter was about 0.012 in.

J. J. Stines[4] said that he had found about the same trouble as reported by the author; but he thought that much had been laid to faulty lubrication which was not due to lubricating oil. The oil filter on the engine, fuel-oil conditions before the engine, and many other troubles had been laid to lubrication. The use of air filters had eliminated troubles in one plant, and the change in location of the lubricator had accomplished it in another.

He had found, as the author had explained, that the pocket through which oil was injected into the cylinder became corroded and filled up with carbon. The oil came in one pipe and then branched off into two pipes, and as soon as one pipe clogged up the oil went the other way.

Carl L. Johnson[5] said that while lubricating oil was cheaper than cast iron, many companies were trying to use the cheapest oil they could buy in spite of the final results.

He had experimented with a cheap oil, which had been shown by laboratory test to be unfit for use, by putting it in an old engine. After one day's running the asphaltic content went up to seven per cent.

[2] De La Vergne Machine Co., Kansas City, Mo.

[3] Worthington Pump & Machinery Corporation, Kansas City, Mo.

[4] Prairie Pipe Line Co., Kansas City, Mo.

[5] Manhattan Co., Kansas City, Mo.

Modern Automobile Production Methods

WITH the exception of improved and labor-saving machinery, the principal development in production methods has come through the efforts to have material flow smoothly in a continuous line from the receiving and stock rooms to the shipping rooms. Formerly we carried the work to the machines. Now we take the machine to the work. Similarly, plants were constructed without specific regard to their later utility or their adaptability to manufacturing operations other than those for which they were to be used first. Manufacturers have revamped their buildings and relocated their various operations so that there is the least possible interruption or loss of energy in moving the material from the first to the last stages of production. For example, the cylinder block moves steadily from the normalizing oven to the cleaning, milling, boring, and other operations until it reaches the assembly line. Each of the other units or sub-assemblies moves in a steady procession down its particular channel until it reaches the engine assembly line at the point where it is needed and at the time when it is needed.

Machines that formerly were hand operated were later made semi-automatic and then fully automatic. The single-purpose machine of today does not require the highly qualified operator who was needed when the human element played a larger part, and one or two men often can operate four, five, or six machines, with a great saving in labor cost over the methods that were in vogue years ago. There is also a great saving in material, for the uniformity and greater accuracy of machine operation reduce the spoilage of material by hand operation.

An advancement that has been a blessing especially to the smaller factory is the development of machines capable of adjustment to take care of differing types of work. For example, standard milling machines can be converted to a number of special uses that would otherwise require machines of special design and construction, the cost of which would be prohibitive.—W. K. Swigert in *Journal of the Society of Automotive Engineers*, September, 1927, p. 286.

Smoke-Abatement Methods Used in Cleveland

By ELLIOTT H. WHITLOCK,[1] CLEVELAND, OHIO

THE history of the Smoke Department of the city of Cleveland is probably characteristic of that of most smoke departments, and some facts may be gathered from a brief study of the past.

After the adoption of an ordinance by the City Council, the Department of Smoke Abatement was organized about July, 1900, under the direction of Prof. C. H. Benjamin, who was then professor of Mechanical Engineering at Case School of Applied Science. Professor Benjamin gave only part of his time to the work of the department, but was able to organize it efficiently as is shown by the figures given in his first report, submitted in July, 1901. During that year he reported 114 mechanical stokers installed, 14 down-draft furnaces, and 44 automatic smoke preventers. It is also interesting to note that he reported the reading of 57 chimneys from a given point in September, 1900, with an average for the day of 10.4 per cent of smoke, and similar observations made on the same chimneys in June, 1901, averaging only 5.4 per cent of smoke.

The successor of Professor Benjamin remained at the head of the department for eight years, or to 1910, from which time to the present the terms of the various incumbents have been short, running as follows: 2 years, 3 years, 1 year, 2 years, 4 years, 8 months, 1½ years, 1½ years, and 1½ years to the present writing. The appropriations for the operation of the department also show a lack of continuity in the work, in that the amount of money used in 1922 was less than half that in 1921.

O. P. Hood, Chief Mechanical Engineer, U. S. Bureau of Mines, has emphasized and elaborated on the necessity for a continuing policy in smoke-abatement work if permanent results are to be hoped for. In one of his articles he compares the handling of the smoke departments of our cities with that of other city departments, such as the water, sewer, and police, all of which have well-defined programs projected over a number of years. He says in one instance, "One characteristic of a successful smoke-abatement movement is continuous, never-ending pressure."

The conditions in Cleveland today with regard to the smoke nuisance are not at all what might have been expected had the policy established by Professor Benjamin been carried out from the start to the present time.

Ordinances

It is quite amusing to read the ordinances on smoke abatement from several different cities and note the different angles from which those framing the ordinances have attacked the problem. One noticable ambiguity which is still allowed to continue in many ordinances is the use of the words "dense smoke," with absolutely no definition of the meaning of the words. This condition obtained in the Cleveland ordinances until about a year ago, when they were changed to define the meaning of the words by specific reference to the Ringelmann Chart. These charts are well known and are published and distributed (free of cost) by the U. S. Bureau of Mines. It is quite evident that the Court—at least in Cleveland—accepts this definition of smoke, since in not one instance has the department prosecuted an offender without receiving a conviction accompanied by a fine, and in no case has the fine been remitted by the Court.

Many ordinances, including the present Cleveland ordinances, are ambiguous in defining the scope of equipment intended to come under control of the department. In attempting to qualify certain features of certain sections of the code, the meaning of the original section becomes involved and is thereby susceptible of more than one interpretation. For example: It has long been the custom in Cleveland to require no permit for any furnaces of a capacity less than 1200 sq. ft. of steam radiation. It seems to the author that this is a misinterpretation, since the limitation applies only to a type of furnace of a given size and should not be considered as a limitation on the size of the plant. Other ambiguities occur in many ordinances which no doubt will be rewritten in due course as our experience becomes more extensive. It will be very helpful, too, if there can be prepared and recorded with the ordinances certain physical relations, such as maximum size of boiler to be allowed with hand-fired grates, setting heights for boilers both hand-fired and stoker-fired (these may vary in different sections of our country due to the different kinds of fuel in use), limiting or excluding the installing or use of certain types of equipment which are impossible or difficult to operate without making smoke, etc. Some such published data would assist materially the engineer, the architect, the owner, and the smoke department. The suggested "Standard Ordinance" proposed by the A.S.M.E. is a good start in the right direction, but it will probably have to be modified or expanded somewhat for local conditions.

Equipment

Time, temperature, turbulence—if these three elements, or any one of them, are overlooked or slighted in the design of combustion equipment, the ultimate owner or operator will be penalized by having to pay an unnecessary tax for the imperfect combustion of his fuel. Also the smoke department will have a potential offender on its hands. Too many times a piece of combustion apparatus is designed for use with a fuel of certain known characteristics, and later on is exploited commercially in a field where fuel of an entirely different composition is used. Hence inefficiency and smoke.

Apparently the suggestion of imperfect combustion in the form of smoke brings to the mind of most people the vision of a power plant of moderate size. If such plants produced the most smoke it might be a comparatively easy matter for a smoke department to prove to the owners the economy which can always be promised upon making one or more commonly known and accepted changes, with very moderate investment, which would eliminate the smoke. To prove that this is not mere verbiage, two of many such letters on file in the Cleveland Smoke Department are reproduced.

> We are very glad to report that since we completed the changes in our boiler arches in accordance with your suggestion, we have practically eliminated all of our smoke. We are indeed grateful to you for your recommendations, for, as you know, when we are operating at full capacity, our boiler is well overloaded and as a result we have been obliged in the past to burn fuel oil along with our coal in order to keep up full steam pressure. Since the installation of the new arches we have been able to maintain a full head of steam and practically eliminate the use of oil.
>
> As we were using approximately 300 gallons of fuel oil per day before we changed our boiler arches, this saving will soon compensate for the extra expense involved in making the changes in our boiler.

Another letter runs as follows:

> Replying to your letter of November 3, would advise you that we installed during the first part of July one of the. . . .stokers, and we are pleased to give you the following experience with same.
>
> For the month of August we averaged 4.3 tons of coal per day. Our previous average was 5 tons of coal per day. The coal used during August was 65 cents a ton less than the other grade of coal.
>
> The saving in the amount of coal and difference in price amounted to $6.30 per day.
>
> Our direct labor for fireman and engineer figured a saving of $1.95 per day, making a total saving on each day operated of approximately $8.25.
>
> It is needless to say from the above figures that we are very well satisfied with the performance of the. . . .stoker, and also believe that it has eliminated the trouble we have had with your department due to excessive smoke.

Other letters showing even more startling amounts of savings are on file. Such information soon convinced the Cleveland Smoke Department that smoke abatement should and could be "sold" to the smoke offenders on the basis of an economical investment on which generous returns might be expected, even more generous returns than are customary on stocks or bonds which are so keenly sought for on the stock exchange, for it is seldom that stocks or bonds will amortize the principal investment in a period of two years, which is a condition that can frequently be shown by improved combustion.

The lack of sufficient oxygen to mix with the gases of the high-

[1] Commissioner of Smoke Inspection, City of Cleveland. Mem. A.S.M.E.

For presentation at the First National Meeting of the A.S.M.E. Fuels Division, St. Louis, Mo., October 10 to 13, 1927.

volatile bituminous coals used in Cleveland, and other places, is one cause of serious trouble and loss. This can be definitely figured for any assumed conditions, and Fig. 1 shows both in figures and graphically the loss due to 8 per cent too little air and the economy of 40 per cent excess air when burning coal with 37.61 per cent of volatile matter. In the one case there is smoke, in the other a clear stack. In the one case there is a loss of 75 cents per ton of coal, when the cost is $4.50 per ton, and in the other this 75 cents per ton is saved.

In Fig. 1, the left-hand circle represents the combustion of one scoopful (20 lb.) of the coal selected, which is a coal purchased anywhere in the Ohio markets, when burned with 91.6 per cent of the required amount of air. The right-hand circle represents the same coal when burned with 40 per cent excess air, assuming that the conditions of the boiler plant are the same in both cases.

But to come back again to the subject of equipment, there are so many general divisions with their attendant subdivisions that complications arise as soon as one attempts to establish any definite rules to be followed. For instance, "stationary" boilers may be subdivided into classes as power, heating, processing; "portable" boilers into those for cranes, shovels, rollers; "marine" boilers into those for vessels—freight and passenger, tugs, scows, derricks; and "locomotives," with their innumerable designs from obsolete to modern. In all these various subdivisions customary methods of setting and operation necessitate a special study of the problem in order to produce better combustion and less smoke. Such varied conditions are no doubt responsible for the long delay in establishing definite rules that might be published and adopted for general use.

Then, too, the fuels that can be obtained in the markets in different parts of our country, with their varying chemical compositions and physical properties, still further complicate the problem. However, it is encouraging to note that there are some established requirements that can be applied in many cases, and progress has been made in recommendations that have been published and can be obtained by any who are interested in good combustion. Particular reference can be made to the progressive and excellent conditions agreed to by and between the boiler manufacturers and the stoker manufacturers as one piece of real constructive work along these lines.

In Cleveland it is required that all plans for new equipment be presented to the Smoke Department for approval, and much constructive criticism has resulted in many changes for the better. During the last year and a half permits were issued for 210 new cast-iron sectional heating boilers made by 16 different manufacturers. In very many cases the architect had failed to show a chimney of sufficient area and, what is perhaps still worse, had indicated a chimney height entirely too low to produce proper draft conditions. These defects are always checked and corrected before the building permit is issued. Another peculiar deficiency which is so often found on architects' plans is the entire omission of any means whereby air can enter the boiler room. Why figure the volume and velocity of gases passing out of the chimney if the furnace room is to be hermetically sealed up so that no air can enter the furnace? In Cleveland it is necessary to provide an open fixed louver to the outside air equal in area to the area of the chimney. There were also installed during the last year and a half 136 steel and high-pressure boilers totaling about 20,500 hp. The checking of this work is comparatively easy, as the system established brings the plans into the office, and it was only necessary to take a few cases into Court, where fines were imposed in every case, to convince contractors that the department intended to regulate all new installations.

The versatility of any smoke department is, however, put to the most severe test in its attempt to "sell" its services and knowledge to the owner or manager of an already established smoky plant, in its endeavor to save that owner an appreciable amount of money. All such owners are more or less skeptical, and some are even so stubborn as to make it necessary (after a long time and much patience) to take them into Court on a charge of violating the smoke ordinance before they will listen to reason.

In Cleveland among the chief offenders are the old-style low setting and small combustion space, chiefly on h.r.t. boilers. These may be changed in several ways—by using Dutch ovens, raising

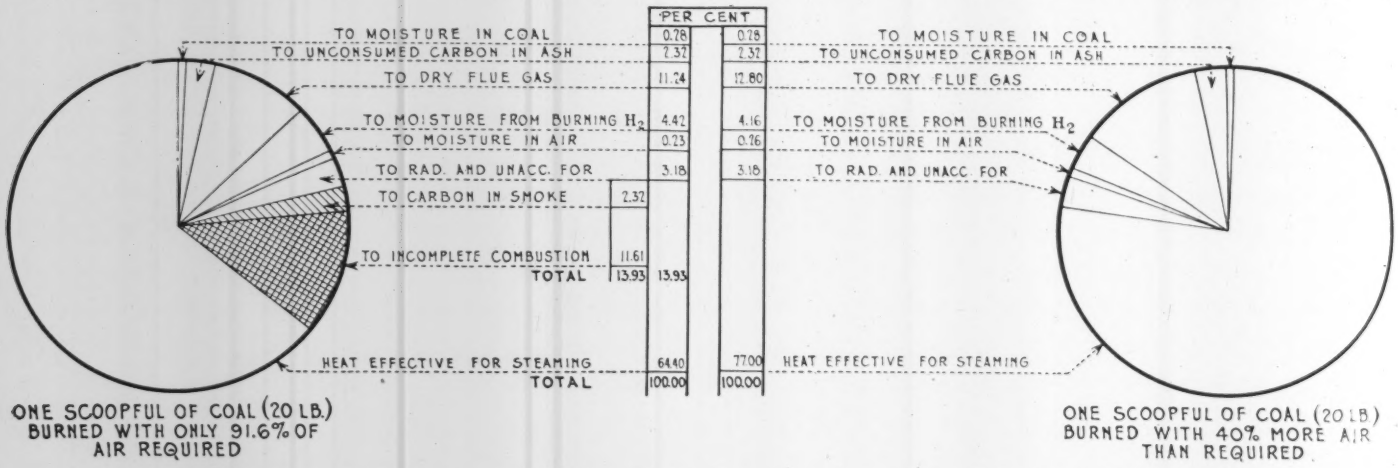
PER CENT
TO MOISTURE IN COAL 0.78
TO UNCONSUMED CARBON IN ASH 7.37
TO DRY FLUE GAS 11.24
TO MOISTURE FROM BURNING H_2 4.42
TO MOISTURE IN AIR 0.23
TO RAD. AND UNACC. FOR 3.18
TO CARBON IN SMOKE 2.32
TO INCOMPLETE COMBUSTION 11.61
TOTAL 13.93 13.93
HEAT EFFECTIVE FOR STEAMING 64.40
TOTAL 100.00
ONE SCOOPFUL OF COAL (20 LB.) BURNED WITH ONLY 91.6% OF AIR REQUIRED
TO MOISTURE IN COAL 0.78
TO UNCONSUMED CARBON IN ASH 2.37
TO DRY FLUE GAS 12.80
TO MOISTURE FROM BURNING H_2 4.16
TO MOISTURE IN AIR 0.16
TO RAD. AND UNACC. FOR 3.18
77.00
HEAT EFFECTIVE FOR STEAMING
100.00
ONE SCOOPFUL OF COAL (20 LB.) BURNED WITH 40% MORE AIR THAN REQUIRED

FIG. 1 LOSS DUE TO TOO LITTLE AIR AND SAVING DUE TO EXCESS AIR IN BURNING HIGH-VOLATILE BITUMINOUS FUEL

boiler, lowering grates, reversing arch back of bridge wall, using Chicago setting, etc. The internal-firebox type and Scotch type require Dutch ovens. Over-fire air provided by steam-air jets is found very helpful and has been advised in many cases, and even in some cases with stokers, where the setting is too low, these jets have proved very efficient.

Of the general improvements made during the last year and a half we might enumerate the following:

Stokers installed	61
Oil burners installed	24
Blast-furnace gas adopted	9
Powdered coal adopted	5
Induced-draft fans installed	2
Steam-air jets installed	67
Special setting changes made	51
Stacks raised in height	63
From fuel to purchased steam	59

STEAM-AIR JETS

The author was unable to find in any publication any comprehensive data on the subject of air jets, even after considerable investigation. This seemed rather strange since air jets have been the subject of many patents for years past. Since data were not available, two seniors in the mechanical course at Case School of Applied Science were prevailed upon to take the investigation of such jets as the subject of their thesis, and they have obtained some very interesting data which it is hoped may lead to the design of a proper and efficient steam-air jet.

These tests show that the efficiency and velocity of the jet are materially increased when the steam nozzle is located about one inch away from the outside end of the air induction tube. A very marked decrease in efficiency and effectiveness is shown when the axis of the steam flow does not exactly coincide with the axis of the induction tube. There also seems to be a rather definite relation

between the steam pressure, the area of the steam nozzle, and the diameter and length of the induction tube. It is hoped that these relations may be established over a practical range so that definite dimensions can be published to meet the varying conditions most commonly found where steam-air jets are recommended by the Smoke Department.

CHIMNEYS

For the smaller sizes of heating plants the boiler manufacturers specify in their catalogs, say, 12-in. × 12-in. or 18-in. × 18-in. or 20-in. × 20-in. chimneys. The builder then orders from the supply yard, say, a 12-in. × 12-in. flue tile—but what does he get? A tile with outside measurements of 12 in. × 12 in. nominal, which gives him 12 per cent less flue area than necessary to handle the gases in case the boiler is to produce the heat required for the building.

The next stock size of flue tile in the Cleveland market is rectangular in shape and about 22 per cent larger in open area than

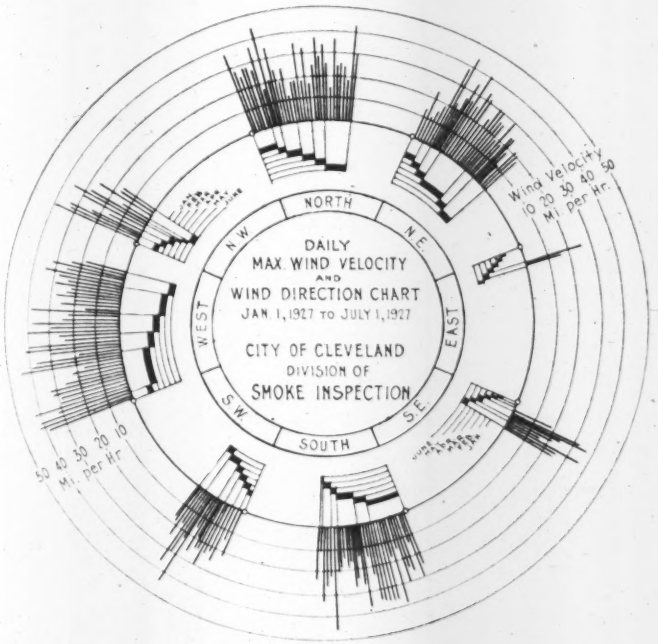

FIG. 2 CHART SHOWING MAXIMUM VELOCITY AND DIRECTION OF WIND AT CLEVELAND, OHIO, FOR THE FIRST SIX MONTHS OF 1927

necessary. One wonders whether the tile makers are trying to force the builders to use certain sizes of tile or whether neither they nor the builders (and even the architects) have any conception of the real function of a chimney.

It seems appropriate to suggest that the Department of Commerce might very properly include some work on this subject in their program of standardization of commercial products. If such an organization would undertake this work it would save a great deal of time and would be acceptable to all smoke departments; if the various smoke departments undertake the task there is liable to be confusion among the various standards which they may adopt.

Another astounding lack of uniformity in chimney sizes is very evident when one compares the published net ratings of several cast-iron boiler manufacturers with their published required areas and heights of chimney for similar loads.

Of course the height of chimneys is a bone of contention between the Smoke Department and the architect, owner, and contractor. In the Cleveland department the chimney size and height are established and marked on the original plans submitted to the Building Department; the building inspectors watch carefully and report any discrepancies to the Smoke Department as soon as discovered, and the work on the building is stopped until the matter is adjusted. The smoke inspectors also carry tickets for all new work under way in their respective districts, and they check from time to time the chimney sizes. These tickets also serve as a check against any one installing a boiler without first having secured a proper permit from the Smoke Department.

The author ventures to offer the following as a truism: If ten stacks in an adjacent area are all accustomed to smoke, the general public notice the condition in a general way. Now when nine of these stacks are improved and stop smoking, the one remaining offender attracts much more notice and unfavorable comment from the same general public. In other words, the more nearly the Smoke Department in any city accomplishes smoke abatement, the more patience, self control, and forbearance the members of the department must have.

INSTRUMENTS

How many people in any city can tell in comprehensive language just what a chimney is for, how it functions, and how its effectiveness can be measured? How many know that the steam output of a boiler can be accurately metered the same as gas, electricity or water? How many know that there are meters (both recording and indicating) to show the fireman whether he is using air enough to burn his coal or not? How many know that no matter how far down or out of sight of the top of his smoke stack the fireman may be, there is an instrument which will show him at all times the amount of smoke he is making? Engineers are supposed to know all these things and a few more, hence we must conclude that the evidence offered by the lack of such instruments in, say, 95 per cent of the boiler rooms of any city is prima facie evidence that the engineer is a very poor salesman. Of what use would a clock on the mantel be if it were lacking hands and face? The works are there, but who would know whether they were functioning or not? Is it not equally as ridiculous to install chimneys and boilers without some means of telling whether they are "keeping time" or not?

WIND

Wind—velocity and direction—has much to do with the daily appearance of the atmosphere immediately above a city. While, as

FIG. 3 ROAD ROLLER DRIVEN BY INTERNAL-COMBUSTION ENGINE

yet, we in Cleveland have had no time to seriously study the effects of wind on our problem, we are keeping the subject in mind and have roughly concluded that any day showing a wind velocity of less than 15 miles per hour will appear as a smoky day, regardless of the direction of the wind. Fig. 2 gives the direction and velocity of the wind for a six-months period at Cleveland as reported by the U. S. Weather Bureau.

EDUCATION

The more knowledge that is broadcast on the subject of combustion and firing, the better will be the conditions as to smoke abatement. For the past year and a half in Cleveland there has been conducted a night-school course for firemen which has been attended by more than a hundred students who have received valuable instruction, both by lecture courses and practical demonstration.

One of the old, well-established colleges in the East has sensed the lack of well-informed combustion experts and is starting this fall an entirely novel course entitled "Fuel Engineering." On being graduated from this course a degree of Master of Science in

FIG. 4 FIRING HIGH-VOLATILE COAL UNDER BOILER OF RAILROAD CRANE WITHOUT OVER-FIRE AIR

Fuel Engineering will be awarded. It would seem that such a course would be of inestimable value to any one expecting to take up combustion work or smoke-abatement work.

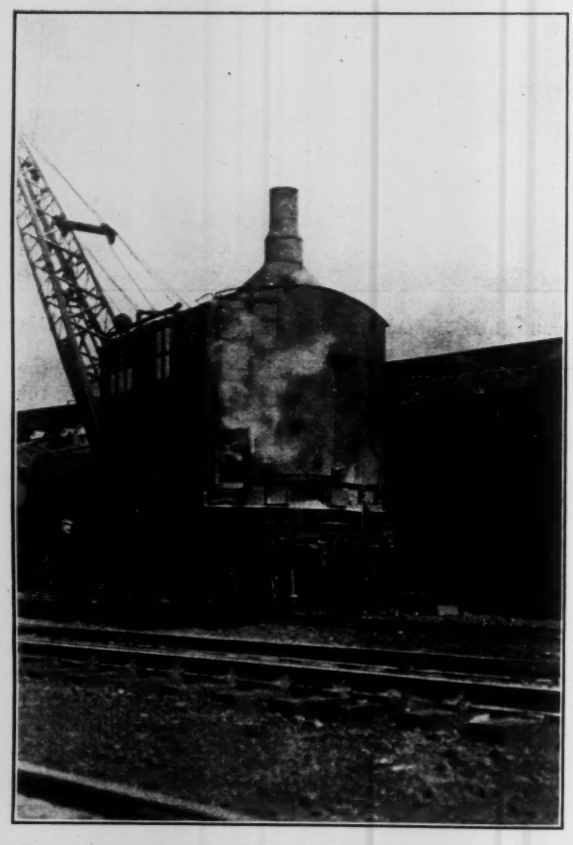

FIG. 5 FIRING HIGH-VOLATILE COAL UNDER BOILER OF RAILROAD CRANE WITH STEAM-AIR JETS IN USE

SOOT-FALL TEST

The Health Council of Cleveland has started as of June 1, 1927, a so-called "soot-fall test," and is collecting data from ten stations about the city that will give the total deposit at each station; these deposits are then to be analyzed to determine their percentage content of ether extract (presumably tar), fixed carbon, ash, and Fe_2O_3. Since there have been two previous tests of similar character made in Cleveland, one in 1920 and one in 1924, it will be interesting as well as instructive to compare the results. Sufficient data are not yet available to warrant any comparisons. It might be of interest, however, to state that the 1924 test showed the heaviest deposit—in the down-town section—to be 2038 tons per square mile per year, while the lightest deposit—in a residential section—was 83 tons per square mile per year.

Returning for a moment to various forms of equipment, we might mention the fact that at the request of the Smoke Department of Cleveland the Street Paving Department have changed their fuel for tar kettles, asphalt heaters, and such portable equipment from wood and coal over to oil, and report satisfactory results, with some economy and elimination of the objectionable smoke.

Internal-combustion engines are being used on road rollers with satisfactory results, as shown by Fig. 3.

The railroad crane, which usually causes considerable annoyance to smoke departments, can also be improved appreciably by the use of over-fire air in the form of steam-air jets, provided of course that the operator is conscientious in using them each time that he fires. Figs. 4 and 5 show the same crane with jets turned off and turned on.

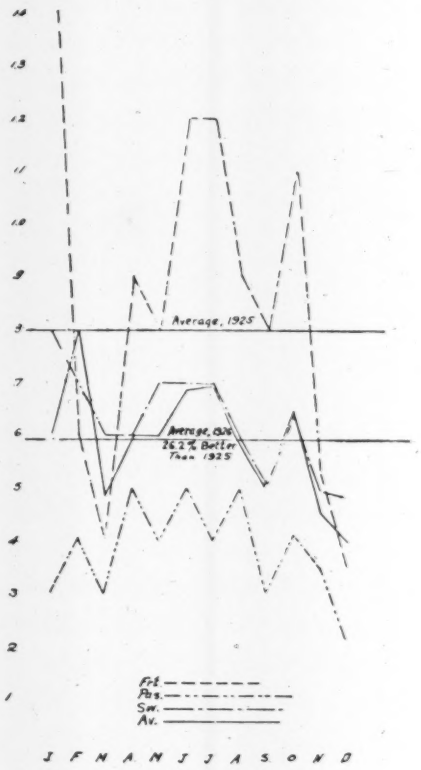

FIG. 6 PERCENTAGE OF SMOKE FOR EIGHT RAILROADS IN CLEVELAND

RAILROADS

In the Cleveland district the railroads are coöperating very earnestly with the Smoke Department and have accomplished some very commendable results. A direct comparison between the year 1925 and 1926 is justified from the fact that the operations were carried on in the same manner and by the same inspectors. Taking the average results of the year 1925 as the base figure, those for 1926 show an improvement for the year of 26.2 per cent. The monthly results for each kind of service—passenger, freight, and switching—for the year 1926 were plotted and are shown by the curves of Fig. 6. It is quite evident that the freight service falls far short of the good results shown by the other two classes of service. These curves represent the combined averages of eight different railroads in the Cleveland district. A unique feature of the interest shown by the railroads in smoke-abatement work is the fact that on one day each month from twenty to thirty men from the eight roads meet in the office of the smoke commissioner to discuss the problem both as regards detail violations as well as general methods and means for abating smoke. The results of experiments on one road are here discussed and passed on to the other roads. The men who attend these meetings are the master mechanics, road foremen of engines, traveling firemen, assistant superintendents, superintendents of locomotive operation, general foremen, shop foremen, superintendents of fuel conservation, and smoke inspectors.

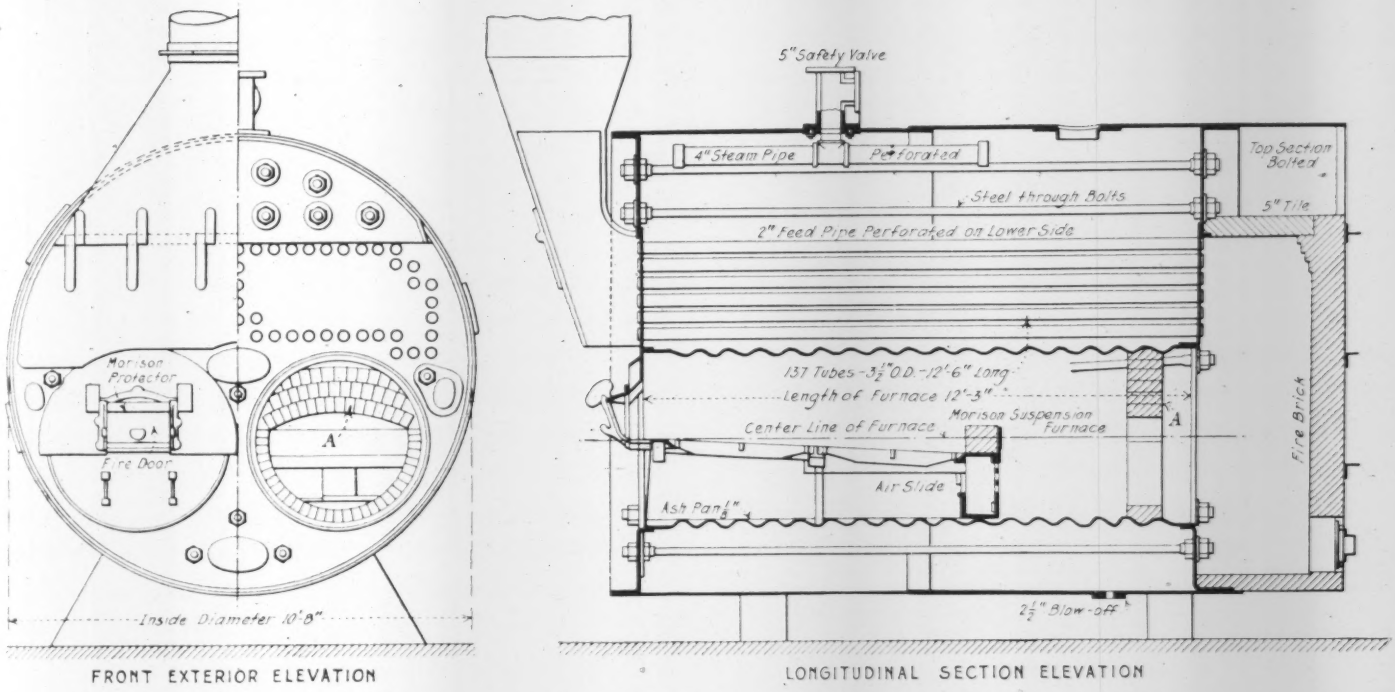

FIG. 7 REVERSE FIREBRICK ARCH INSTALLED AT REAR OF FURNACE FLUE OF A SCOTCH MARINE BOILER

MARINE

Cleveland, together with a few other cities, has the additional problem of vessels on the lake front and river. Concentrated work in this line had not been started till the spring of 1927. A study of the conditions on the boats revealed the same general characteristic lack of appreciation on the part of the designers of the necessity for sufficient draft and air. The space about the boilers is usually so cramped that it is difficult to apply any additional equipment in an endeavor to improve combustion conditions. Improvement in the smoke condition has been effected in many cases by changing the firing methods, by alternating the time that the crews clean their fires, and by a more careful check by the engineer on watch. Some minor changes have been made, such as putting latches on the fire doors to hold them open to get over-fire air, arranging the ashpan doors so they may be conveniently operated, and running the engine exhaust into the stack to give induced draft. In one case the front was moved out from the boiler to allow over-fire air, and a reverse arch of firebrick was installed at the back end of the furnace flue.

Fig. 7 shows a typical reverse arch (A) at the rear end of a Morison furnace such as was used in the case above cited.

A few of the lake vessels have water-tube boilers, and two of these are stoker-fired. The latest stoker-fired water-tube boiler equipment is in a new vessel which was completed in July. We feel that we are just making a start on the marine work in Cleveland, and have hopes that a more noticeable reduction of the smoke nuisance from vessels will be possible next year.

CONCLUSION

No attempt has been made to explain the detail routine of the work of the Cleveland Smoke Department other than to refer to one or two specific applications. A smoke department, above all things else, must have connected with it a competent technical-graduate engineer, well versed in combustion. No new fuel-burning equipment should be allowed to be installed without a permit from the smoke department. With these two conditions well established, any smoke department can well be expected to produce satisfactory results.

Engineering and Physics

IT IS sometimes stated that the physics of today becomes the engineering of tomorrow. This is a more natural development, since the engineer is more concerned than the physicist with the practical application of physical discoveries. But the converse is frequently true, for many physical discoveries and inventions arise in difficulties encountered by the engineer.

Most discoveries in physics arise from some experimental fact discovered more or less accidentally. The discovery of Röntgen rays was accidental, and the enormous strides which have been made in our knowledge of the atom by J. J. Thomson, Rutherford, Bragg, Born, and many other physicists during the last thirty years have resulted from Röntgen's discovery combined with another great discovery in pure thermodynamics, Planck's quantum theory, which also arose from an accidental discovery made in the course of experiment. The Reichsanstalt in Berlin had published a family of curves representing the distribution of energy in the spectrum of a hot black body. Professor Wren by trial and error obtained an equation to the family, and the form of this equation was suggestive. Planck in trying to develop this equation from the laws of thermodynamics, found that he could only do so by assuming that energy is not indefinitely divisible, and he coined the term "quantum" to represent the fundamental unit. These two discoveries of Röntgen and Planck form the starting-point of that most important branch of modern physics which has increased our knowledge of the constitution of matter, a science which is just beginning to find its field of application in engineering practice, as in the thermionic valve and the modern power transformers on the same lines.

In reviewing the discoveries in physics which have had most effect in developing new industries, and thus calling forth new inventions, one is struck by the great results in this respect which have arisen from application of the second law of thermodynamics, first as stated by Carnot in 1824. Carnot described his ideal heat engine, and showed that the efficiency of this engine is independent of the working substance used. Looking back upon the history of the science of thermodynamics of the last century, it is unfortunate that no one seems to have employed this statement of Carnot's as a general text, and developed it to find what information could be derived from it by using different working substances and mixtures in order to discover something about all the substances used. Had any one done so, progress might have been greatly accelerated. (Prof. Sir James B. Henderson, D.Sc., in Presidential Address to Section G of the British Association, delivered at Leeds, September 1, 1927.)

The Characteristics of Modern Stokers

Characteristics Demanded of Modern Stokers and the Way in Which These Requirements Are Met by Traveling-Grate and Multiple-Retort Underfeed Types—Air Control Along Length of Retort and Duplex Firing of Multiple-Retort Underfeed Stokers

By F. H. DANIELS,[1] WORCESTER, MASS.

BEFORE going into the subject of the characteristics of modern stokers, it will be well first to establish some definitions in order that it may be understood just what is being referred to. The Stoker Manufacturers Association have adopted a certain nomenclature in reference to the classification of the different types of stokers. These definitions are as follows:

Definitions

1 *Grate.* A grate is a metallic structure designed to support fuel, and so made that air for combustion can pass through the grate to the fuel.

2 *Mechanical Stoker.* A mechanical stoker is a device consisting of a mechanically operated feeding mechanism and a grate, and is used for the purpose of feeding solid fuel into a furnace, admitting air to the fuel for the purpose of combustion, and providing a means for removal or discharge of refuse.

3 *Overfeed Stoker.* An overfeed stoker is a stoker where fuel is fed on to grates above the point of air admission. Overfeed stokers are divided into three classes, as follows:

a A front-feed inclined-grate stoker is an overfeed stoker where fuel is fed from the front on to a grate inclined downward toward the rear of the stoker.

b A double-inclined side-feed stoker is an overfeed stoker where the fuel is fed from both sides on to grates inclined downward toward the center line of the stoker.

c A chain- or traveling-grate stoker is an over feed stoker where the fuel is fed to the stoker from the front on to a moving grate forming an endless chain.

4 *Underfeed Stoker.* An underfeed stoker is a stoker where the fuel is introduced at a level below the point of air admission.

5 *Multiple-Retort Stoker.* A multiple-retort stoker is an underfeed stoker consisting of a number of troughs or retorts placed side by side with a coal-feeding mechanism at the front end of the retorts and provided with ash-disposal means located at the rear end of the stoker.

As a general rule, the tendency of the times is undoubtedly toward larger power-plant units of all kinds. This is brought about by economic reasons, in accordance with the old, familiar law of the squares and the cubes. The volume, and consequently the capacity, goes up as the cube of the lineal dimensions, while the surface, and thus the radiation and other losses, increases only as the square of these same lineal dimensions. In other words, the larger the boiler, the more efficient it should be. There is also a very noticeable demand for higher and higher boiler ratings. In this paper the author proposes to confine his remarks to the only two types of stokers which are suitable for the larger modern boilers operated at high capacity. These two types are the chain- or traveling-grate stoker and the multiple-retort underfeed stoker. In order to meet the requirements for high capacity, both types must of course be provided with forced draft.

Characteristics Demanded of Modern Stokers

As boilers get larger and larger the amount of floor area available under the boiler becomes less and less per unit of boiler capacity. In other words, a 1000-hp. boiler will not have twice the floor area under it that a boiler rated at 500 hp. has. The same high overload capacity is desired from a large boiler as from a small one. This means that in most cases the stoker must be so designed that it can be built in lengths equal to the maximum space which is available, and there must be no limit whatever upon the width of the stoker, because the entire space under the boiler must in most cases be utilized for fuel-burning area. The growing use of water walls in the furnace whereby much of the water-heating surface is located on the vertical walls instead of in the boiler proper still further intensifies reduction in the floor area available per unit of boiler capacity, and at present the stoker manufacturer is many times at a loss to know where to put sufficient coal-burning area under the boiler in order to get the capacities wanted. The first characteristic of modern stokers, therefore, must be that there must be no limitation on size. It must be possible to build the stoker as large as the floor area that is available, and, if the floor area is limited, the stoker must be capable of high rates of coal burning.

The second characteristic is that the stoker must be able to meet sudden overload demands with no appreciable drop in steam pressure.

The third characteristic is that the stoker must be provided with an automatic and continuous ash-discharge mechanism.

The fourth characteristic is that the stoker must be capable of being operated with preheated air. In order to prevent too much air at the rear end of the stoker, the pressure of air under each section of the stoker from front to rear must be under the control of the operator. This was formerly not so necessary with short stokers, but it has now become important feature.

In addition to these characteristics which should be possessed by the stoker, it is also essential that above the stoker there should be means provided for preventing stratification of gases, i.e., the richer gases coming off at the front end of the stoker should be forced to mix with the leaner gases coming off at the rear end so as to insure uniform quality of gas going to the boiler heating surface. Taking up the two types of stokers, it will be shown how they meet the requirements that have just been set forth.

Traveling- or Chain-Grate Stokers

The traveling- or chain-grate stoker has been built in widths up to 24 ft. and in lengths up to 23 ft. of fuel-supporting area. The length referred to is the distance from the inside of the coal gate to the point where the grate changes its shape from a plane to a curved surface at the rear end. In other words, the area is only actual fuel-supporting area where combustion is taking place. Multiplying these two dimensions gives a maximum fuel-burning area of 552 sq. ft. Figuring 40 lb. per sq. ft. gives an economical coal-burning rate of 22,000 lb. per hour, which would correspond to a 2500-hp. boiler at about 200 per cent of rating. The same stoker would have an easy peak capacity equal to 250 per cent of rating on the same 2500-hp. boiler, or about 200,000 lb. of steam per hour. This stoker requires as a necessary part of the furnace design a front arch, and consequently the space under the boiler imposes no limit on the length of the stoker since the stoker may extend out in front of the boiler without forcing a detrimental furnace design. It should be noted that it is possible to arrange two chain-grate stokers back to back in a single furnace, thus doubling the possible maximum capacity or giving an evaporation of about 400,000 lb. of steam.

While the traveling-grate stoker gives a quick response to overload demands, it is not quite as good for this purpose as the underfeed. The reason for this is easily seen because the depth of fuel bed on the traveling grate is only about 4 to 8 in. as compared with 1 ft. to 2 ft. 6 in. on the underfeed. Consequently there is less of a reservoir of coal in the furnace from which to draw heat when the demand for steam comes. Fig. 1 shows what can be accomplished in this respect with a traveling-grate stoker.

In regard to ash discharge, there could be nothing more continuous or automatic than the manner in which the traveling grate gets rid of its ash refuse. The very design of the grate in the form of an endless-belt conveyor is ideal for ash dumping.

[1] President, Riley Stoker Corp. Mem. A.S.M.E.

For presentation at the First National Meeting of the A.S.M.E. Fuels Division, St. Louis, Mo., October 10 to 13, 1927.

Preheated air at a temperature of from 400 to 500 deg. fahr. has been used successfully on traveling-grate stokers. The relatively thin fuel bed on the traveling-grate stoker, ranging from perhaps 4 to 8 in., necessitates the use of a number of compartments from front to rear, the air pressure in each compartment being controllable at will. The natural-draft chain-grate stoker is of course not suitable for high capacities, and merely applying forced draft to a natural-draft stoker never worked out successfully due to the tremendous amount of excess air which was forced up through the rear end of the stoker where the fuel was practically burned out and the fuel bed porous and open. The idea of putting in compartments on the traveling- or chain-grate stoker and controlling the air in each compartment in accordance with the fuel-bed conditions made the chain-grate stoker a suitable unit for use under high-capacity conditions. With the chain-grate stoker the recent addition of the rear arch gives proper mixing of the gases in the furnace at the throat, and prevents the lean gases from reaching the boiler tubes before they have had a chance to meet the rich gases from the front arch. This insures that combustion will be more nearly completed in the furnace, so that secondary combustion in the space between the boiler tubes is either completely eliminated or greatly reduced. This arrangement adds much to the economy of operation. Fig. 2 shows an ideal furnace arrangement of front and rear arch.

MULTIPLE-RETORT UNDERFEED STOKERS

The multiple-retort underfeed stoker has been built in lengths up to 20 ft. This is generally about all the space which is available under a boiler, and corresponds roughly to a horizontal water-tube boiler with 22-ft. tubes. The underfeed stoker has been built in widths up to 32 ft. On the question of lengths, two underfeed stokers of course can be put back to back with dump in the middle, giving the maximum possible depth of 40 ft. There is no reason why stokers of this type cannot be built 40 ft. wide also. Taking the above dimensions, 32 ft. wide by 40 ft. deep, using two stokers back to back, gives a coal-burning area of 1280 sq. ft., which gives an economical coal-burning rate of 60,000 lb. per hour, equivalent to 15,000 hp., or an evaporation of about 450,000 lb. per hour. The corresponding easy peak capacity would be about 600,000 lb. of steam per hour.

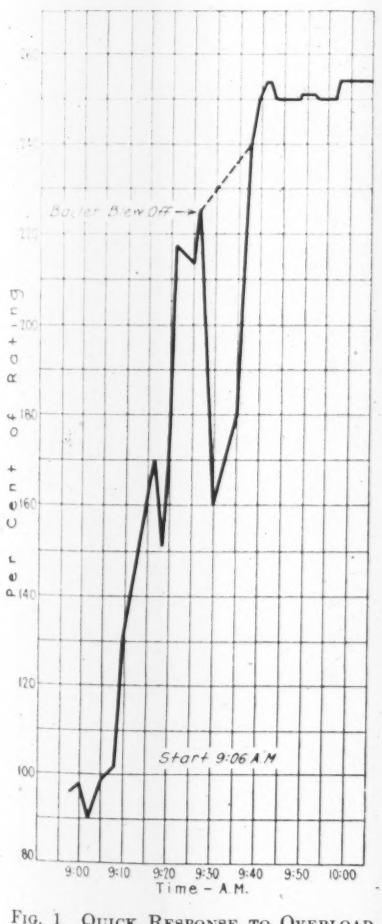

FIG. 1 QUICK RESPONSE TO OVERLOAD DEMAND OBTAINED WITH A TRAVELING-GRATE STOKER

Arches are not necessary or desirable for multiple-retort underfeed stokers. In fact, their use is detrimental. This means that the floor space directly under the boiler is about all that can be used for coal-burning area. In many cases with large high-capacity boilers it is becoming difficult to get in sufficient coal-burning area to suit the load demands, especially when water walls are used. The large amount of coal in the fuel bed of an underfeed stoker insures almost instantaneous response to sudden load increases. Fig. 3 shows what has been done in this respect. There is practically no limit to the speed at which load may be increased, provided a sufficiently high air pressure is available under the stoker. The fuel bed in an underfeed stoker contains at all times an amount of coal equal to about that which could be fed in by the stoker during one hour. This gives an idea of the amount of heat that is stored up in the fuel bed waiting only increased air supply to be released.

The successful development of the clinker grinder for the underfeed stoker insured easy automatic ash removal and at the same time it cut in two the ashpit losses due to unburned carbon. These ashpit losses are now so small that it is a question whether it would be worth while to add anything more to the cost of the stoker with a view of reducing them still further.

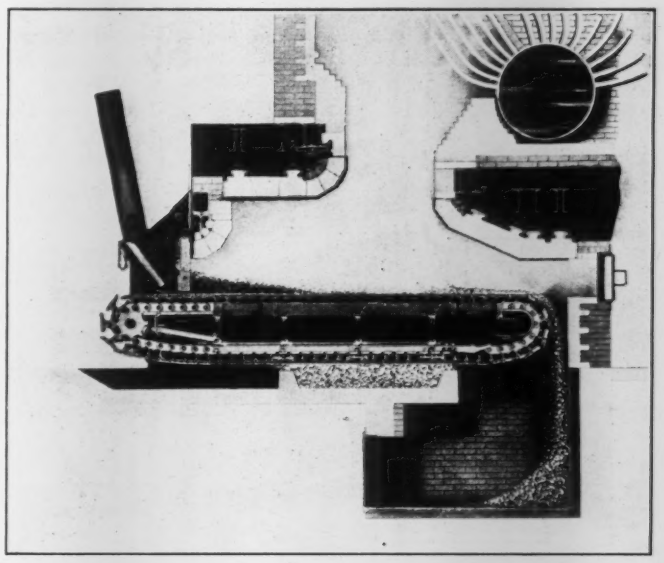

FIG. 2 IDEAL ARRANGEMENT OF FRONT AND REAR ARCH IN CHAIN-GRATE-STOKER FURNACE

FIG. 3 SHOWING RAPID RESPONSE OF MULTIPLE-RETORT UNDERFEED STOKER TO SUDDEN LOAD INCREASE

On preheated air, the multiple-retort underfeed stoker has amply demonstrated its ability to withstand temperatures of from 400 to 500 deg. fahr.

AIR CONTROL ALONG LENGTH OF RETORT

It has long been customary to supply a separate air control to the rear end or overfeed section of underfeed stokers, but the question of controlling the air supply along the length of the retort is just beginning to receive active study and embodiment in practice. The thickness of fuel bed ranges from 1 ft. to 2 ft. 6 in., and consequently there is not as much necessity of air control from front to rear as is the case with the traveling- or chain-grate stoker. It is believed, however, that control of air front to rear on the underfeed stoker would give good returns, and much work is now being done along these lines.

With the long underfeed stokers, especially those with clinker grinders, there is some stratification of gases in the furnace. In an attempt to burn out the last bit of combustible in the ash there is always a tendency to get an excess of air up from the rear end of

the stoker. This gives the lean gas. Arches as used on the traveling-grate stoker are impossible for the underfeed stoker, so some other method of mixing must be used to insure the same beneficial results that the rear arch gives on chain-grate stokers. The author suggests that a small unit pulverizer be installed in connection with multiple-retort underfeed stokers, using a turbulent mixing burner installed in the rear wall of the furnace somewhat like the arrangment shown in Fig. 4. This would accomplish a number of desir-

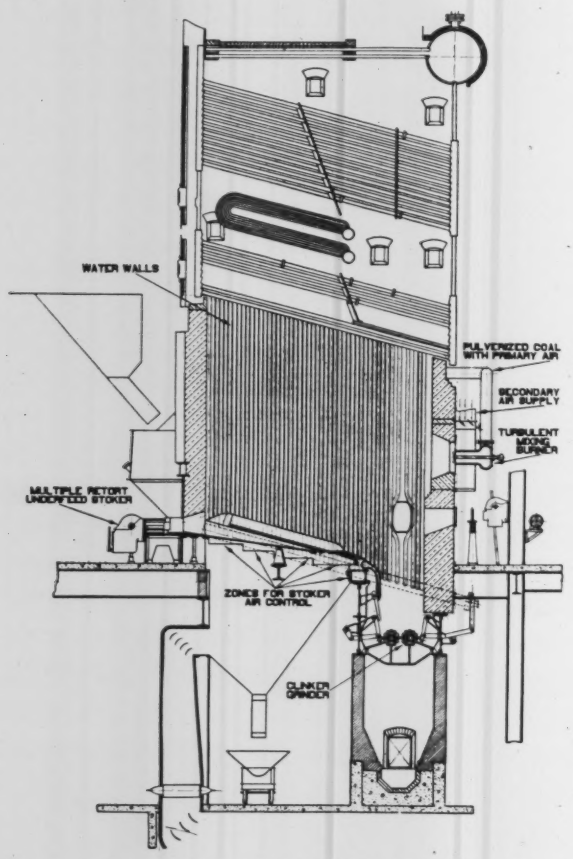

FIG. 4 SHOWING INSTALLATION OF TURBULENT MIXING BURNER IN REAR WALL OF MULTIPLE-RETORT UNDERFEED-STOKER FURNACE

able results. Pulverized coal has one disadvantage in that it is difficult to maintain ignition at extremely low ratings. The stoker, however, with suitable drive mechanism and proper controls can be operated at any rating from a bank up to high capacities. A boiler installation with the duplex firing as suggested would be able to operate at low ratings down to a bank. The unit pulverizer would only be put into service to meet the peak-load demands. The pulverized-coal burner in the rear wall would set up a turbulence in the furnace and would insure the lean gases' coming off from the rear end of the stoker getting mixed with the richer gases from the front end. There would be no loss due to stratification.

In underfeed-stoker operation it is possible to obtain very low carbon in the ash by putting more air than usual through the fuel bed at the rear of the stoker. This method of course means low average CO_2 in the furnace and much leaner gas at the back of the furnace. By using a slight deficiency of air with the pulverized-coal burner the oxygen in the lean gas can be utilized without decreasing the overall economy of operation. The stoker itself with its clinker grinder is well adapted to automatically dispose of the pulverized-coal ash which drops down on the fuel bed. One of the serious problems with pulverized-coal burning is what to do with the ash that collects on the bottom of the furnace. It is in the form of finely divided particles which blow away when there is the slightest wind, so it is difficult to use it for fill. It is not easy to wet it uniformly so that it can be handled without making a dusty job. With the proposed duplex firing the small amount of powdered-coal-ash dust would be so mixed in with the more plastic stoker ash and clinker as to not affect the ready sale of the resulting product. There are many successful underfeed-stoker installations where blast-furnace gas is used as an auxiliary fuel fired in the furnace over the stoker. There would be very little possibility of damage to the stoker parts on account of the thick fuel bed used on underfeed stokers, and by leaving a bed of ashes on the stoker it would still be possible in a emergency to run the pulverized-coal equipment without operating the stoker, allowing a bed of ash to protect the grate surface. This duplex-firing scheme offers a solution in cases where there is not sufficient floor area available to give coal-burning capacity equal to the boiler ratings desired. The heat of the pulverized-fuel flame above the stoker fuel bed would insure better burning out of the stoker ash. It seems as though it would be particularly adaptable for central-station use where the maximum output is desired during the peak hours. Large furnace volumes are now regular practice for high-capacity stoker work and no additional space would be needed since this space would merely be better utilized due to the better mixing resulting from the addition of the turbulent powdered-coal burner. For very high capacities water walls would be required, but these are being used now for many stoker installations. The water walls would also reduce the danger of clinkering due to coal of low ash-fusing temperature, and a sufficient amount of water-wall surface must be used to hold

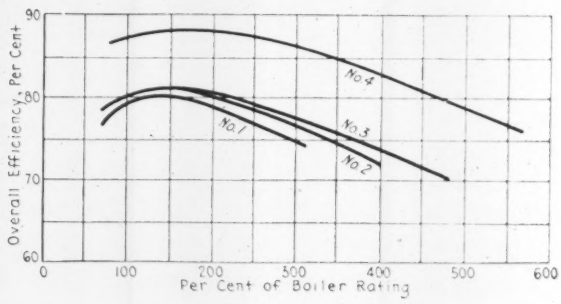

FIG. 5 INCREASED EFFICIENCY AND CAPACITY OBTAINABLE BY APPLYING DUPLEX FIRING OF PULVERIZED COAL TO A CLINKER-GRINDER STOKER

Curve 1—Dump-plate stoker.
Curve 2—Clinker-grinder stoker.
Curve 3—Duplex firing with clinker-grinder stoker.
Curve 4—Duplex firing with clinker-grinder stoker and preheated air.

furnace temperatures down to a reasonable figure considering the quality of the coal to be used. The only increase in cost would be the price of the unit pulverizer and burner, and this would easily justify itself by reason of the increased capacity obtained from the boiler during the peak hours. The tendency of the stoker to show a large drop in efficiency at high capacity would be largely offset and it would not be necessary to sacrifice economy to get capacity.

Fig. 5 shows in a general way what might be accomplished in the way of increased efficiency and capacity by applying duplex firing of pulverized coal to a clinker-grinder stoker both with and without preheated air.

Wear Resistance of Gages

SPECIAL tests by the United States Bureau of Standards to determine the wear of metal used in gages have been carried on with considerable difficulty because of the wear resistance of different metals and on account of many variables encountered in shop gaging practice. It has likewise been exceedingly difficult to secure data which would adequately define the conditions under which test gages might have been used.

One of the experts at the Bureau recently described a laboratory wear tester designed for plug gages. This machine which provides for the repeated insertion and removal of plug gages representing the "work" has been found to give consistent results because of the possibility of closely controlling the gaging conditions.

Supplementary and more extended tests have been made in which test gages were used without abrasives, in steel, aluminum alloy, and cast iron containing appreciable proportions of pearlite, showing that chromium-steel gages had the highest resistance to wear. Ammonia-treated chromium-aluminum steel was next. These were stated to be much superior to the remainder of the group. In general file-soft steel showed better resistance to wear than corresponding steel in the file-hard condition. This difference was most noticeable in an oil-hardening tool steel.

Industrial Furnaces

Importance of Relative Temperatures of Heat-Radiating and Heat-Absorbing Media—Effects on Efficiency of Low CO_2 and Excess Air—Cost of Steam for Blowing

By VICTOR J. AZBE,[1] ST. LOUIS, MO.

COMBUSTION and heat-transfer problems encountered in boiler plants are ordinarily much simpler and easier of solution than those met with in industrial furnaces, kilns, and ovens, which are sometimes even apparently unsurmountable. Further the number of engineers studying and improving boiler installations is almost infinitely greater than the number of those who devote their talent and energy to the more complex and varied subject of industrial furnaces. Due to these contrasts in complexity and in attention given the two branches of fuel engineering, it is not surprising that the inefficiency in the industrial-furnace field is so great. Even the very earliest boilers were not as inefficient as many processes of industrial heating are today. The importance of relative temperature and temperature differential must be realized in a comparison of the efficiencies of industrial and boiler furnaces. In the case of a boiler furnace the temperature differential is high, because of the relatively low temperatures, say, 380 deg. fahr., at which the heat is absorbed by the boiler, while in many industrial furnaces it is low because the heat must be absorbed at a high temperature, say, 1800 deg. fahr.

A boiler furnace, industrial furnace, oven, or kiln must be divided into heat-generating and heat-absorbing portions when an attempt is made to study the overall efficiency in order to determine why it is low. A boiler certainly cannot be blamed for not absorbing the heat in gases below the steam temperature, nor can it also be blamed if heat is delivered to it by the combustion apparatus in such a form that it cannot be absorbed. Boiler efficiencies of 98 per cent are unheard of, nevertheless this is true with a flue-gas temperature of 400 deg. fahr. and 16 per cent CO_2 if the steam temperature is 365 deg. fahr., for under these conditions 98 per cent of the heat above 365 deg. is absorbed and that below this temperature is unavailable. Evidently, if the terminal temperature difference is zero, as it is when the flue-gas temperature is 365 deg. fahr., the boiler efficiency is 100 per cent, and if under these conditions the overall efficiency is low the fault is not that of the boiler but that of the stoker and the combustion space. This principle is emphasized because it plays a very important role in industrial-furnace work, and since it is easiest to understand under boiler conditions.

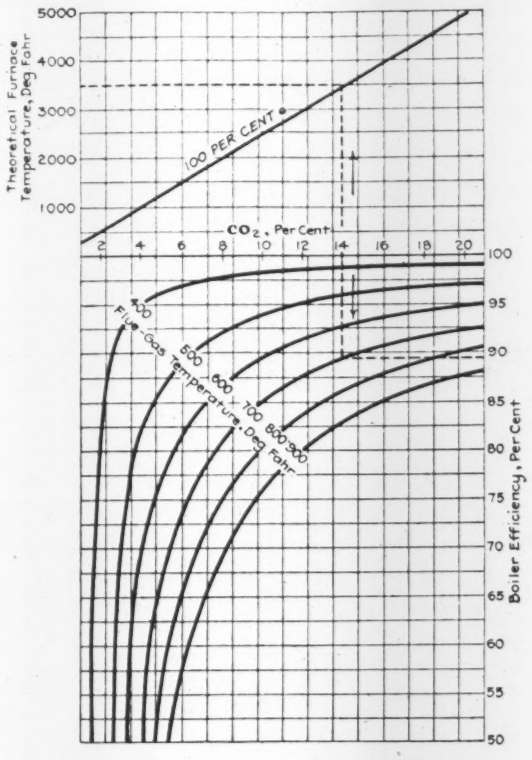

FIG. 1 EFFICIENCY OF A BOILER AS A HEAT ABSORBER

Fig. 1 shows graphically the efficiency of a boiler as a heat absorber. The great importance of high CO_2 is very evident, and this is for the simple reason that high CO_2 means that there is more heat of absorbable character, that is, of high temperature level, and proportionately less of low temperature level. If high CO_2 is important in boiler work, it is ever so much more important in industrial-furnace work. This is shown by Figs. 2 and 3.

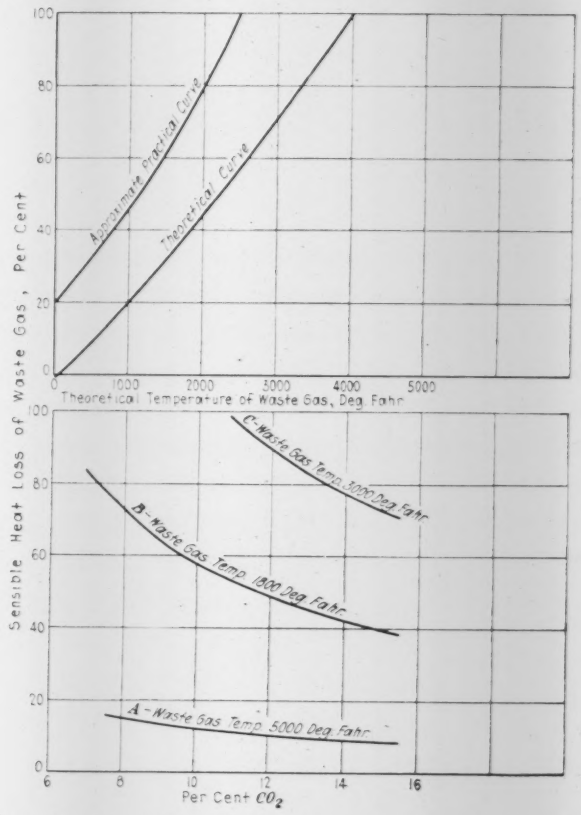

FIG. 2 SENSIBLE-HEAT LOSS WHEN THEORETICALLY CORRECT AMOUNT OF AIR IS USED FOR COMBUSTION

FIG. 3 SENSIBLE-HEAT LOSS FOR WASTE-GAS TEMPERATURES OF 500, 1800, AND 3000 DEG. FAHR., AND EFFECT OF CO_2 WHEN FUEL IS OIL

Fig. 2 gives the sensible-heat loss with different terminal temperatures of gas leaving the furnace with oil as fuel when burned with no excess air, no loss of heat by radiation, and no steam used for oil injection and atomization. It will be noted that the amount of heat available for the process rapidly decreases as the working temperature increases. This decrease is, however, much more rapid if certain other inherent losses are taken into consideration and the approximate practical curve is the more likely one. Both the practical and theoretical curves can fortunately be improved by recuperation, regeneration, insulation, etc.

Fig. 3 again emphasizes the greatly increased loss of heat in the products of combustion with higher terminal temperatures. This

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Contributed by the Fuels Division and presented at the Kansas City Meeting, Kansas City, Mo., April 4 to 6, 1927, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Abridged.

chart further shows the effect of dilution by excess air. Curve *A* representing boiler conditions is not affected very seriously by low CO_2 as compared with curve *B* representing conditions in many industrial furnaces. In case of curve *C* low CO_2 is absolutely fatal except as heat is retrieved by recuperation. In boiler practice 9 or 10 per cent CO_2 is often considered good. The same excess air in the case of a high-temperature apparatus such as a lime or cement kiln would mean that the sensible stack loss is so great that, together with other inherent losses, the efficiency of the kiln becomes zero. This in fact often happens. With any high-temperature apparatus there may be short periods when all the

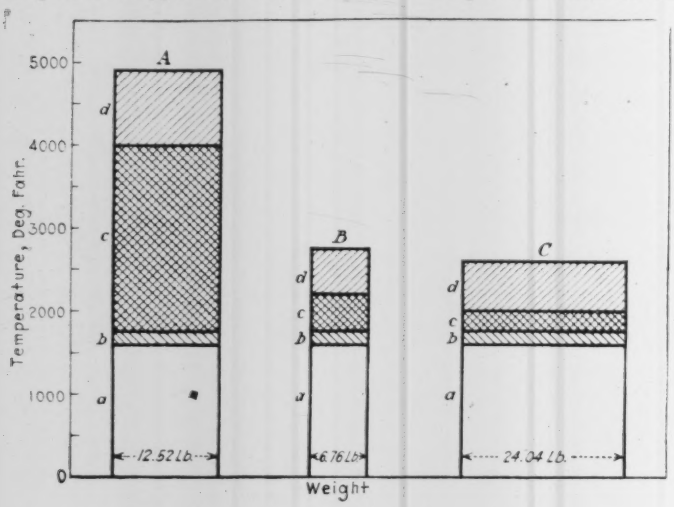

FIG. 4 THEORETICAL AMOUNTS OF HEAT MADE AVAILABLE FOR PROCESS WORK BY ONE POUND OF CARBON BURNED UNDER THE FOLLOWING CONDITIONS: *A*, COMPLETE COMBUSTION AND NO EXCESS AIR; *B*, BURNED TO CO; *C*, BURNED WITH 100 PER CENT EXCESS AIR

(Shaded areas represent heat available for process work; unshaded area represents heat not available.)

Condition	Per cent theoretically available	Per cent practically obtainable
A	63.2	47
B	12.6	5
C	25.5	10

heat put in is at low temperature and none is absorbed. In the case of cement or lime kilns, often for an hour at a time conditions may be such that hot gases entering are cooler than the charge and absorb heat instead of releasing it.

The counterpart of the loss due to excess air is the loss due to incomplete combustion. The seriousness of this loss is graphically illustrated in Fig. 4. The fuel used is carbon. When a pound of carbon is burned to CO_2, the resulting weight of gas is 12.52 lb. and the theoretical temperature of combustion is around 4800 deg. fahr. For the example chosen, all heat above 1600 deg. fahr. is available for use in the process. In Fig. 4, *A* represents this condition. In this figure the horizontal extension represents weight of gas, while the vertical extension represents temperature elevation that would be possible if all heat could be developed before any were taken away. The area thus represents heat. The unshaded area *a* represents the unavailable heat and the shaded areas, *b*, *c*, and *d* represent heat available for the process, but no process will ever use all this heat. Because of a temperature differential necessary to create heat flow, area *b* represents the heat above 1600 deg. fahr. of the gases, which are consequently not cooled down to the product temperature. From every furnace, kiln, or oven there are radiation losses that cannot be entirely prevented. Radiation losses from surfaces at low temperature are not serious, but ordinarily more heat is lost from surfaces at high temperature. These losses are represented by area *d*. The amount of heat available for the process when the furnace is of a very good type is represented by the area *c*.

In Fig. 4, *C* shows how the conditions are modified by the use of 100 per cent excess air; the same amount of heat would be developed, but this heat would be contained in a greater weight of gases and only a small amount—about 10 per cent—would be available for the process.

The situation becomes even more serious when carbon is burned to CO. The weight is small and the temperature is low; the heat available in the process *c* becomes insignificantly small compared with the *c* area in *A*. Consequently one would conclude that in high-temperature work almost all the heat in the carbon that is burned to CO is wasted. While in some processes a reducing atmosphere must be maintained, the great loss due to CO should be kept in mind.

Fig. 5 shows the effect of excess air and of incomplete combustion when the two do not occur simultaneously as is ordinarily the case in such processes as lime and cement burning, that is, processes that have ideal combustion chambers at high temperature so that all free oxygen is sure to combine with whatever combustible gases are present. Curves *A* show the theoretically available amount of heat in the fuel for the process. Under the ideal conditions, if there is no oxygen or CO the amount is 63 per cent, the remainder being unavailable heat at low temperature. As the oxygen or carbon monoxide increases the available-heat curve drops off very rapidly. Curves *B* of the same chart show the existing conditions in actual installation. At the peak 48 per cent is available, and at any slight deviation there is a very sudden drop in efficiency. In actual practice, it is of course impossible to maintain the zero O and CO condition. In some plants the operation will be such that either reducing or oxidizing conditions will predominate, but the fluctuation should be slight and the average should be as close as possible to the ideal. Hand firing almost always is a cause for great fluctuations. Periodically there may be found 10 per cent

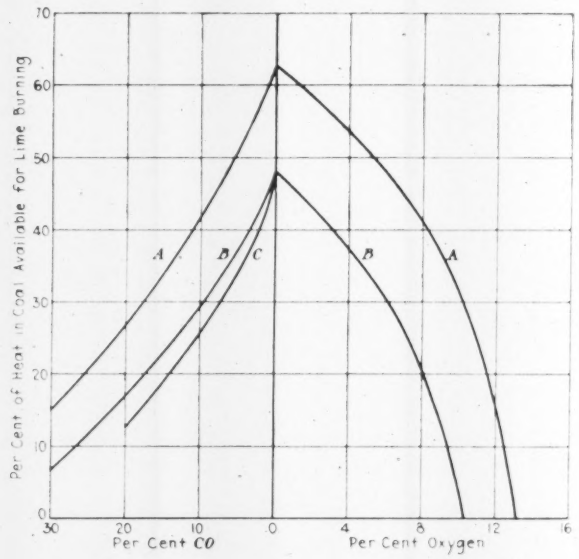

FIG. 5 EFFECT OF EXCESS AIR AND INCOMPLETE COMBUSTION

A Theoretically possible amount of heat in coal available for lime burning

B Practically obtainable amount of heat in coal for lime burning when air is not preheated with waste heat and radiation loss is not abnormal

C Modification of curve *B* considering the fact that with no oxygen when CO is present, CH_4 and H will be present too. Exact location of this curve is not known and cannot be calculated.

CO and then again 10 per cent O, with the ideal condition existing only during a very short portion of the cycle between two firings.

While previously the importance of loss due to incomplete combustion was emphasized, Fig. 5 shows that in high-temperature work, percentage for percentage, oxygen is the less desirable. This of course comes from the fact that with 20 per cent CO there will be still some heat available for the process, but long before 20 per cent O is reached, the gases are at too low a temperature to be useful.

Due to the harm caused by even small deviations from the ideal, it is much to be desired that there be as great regularity as possible. Oil with good burners lends itself well to this purpose; and for many reasons, and with natural gas as the only exception, oil is the ideal fuel for industrial furnaces. Due to the relatively high cost, its use is often prohibitive, in which case the alternatives are stokers and gas producers. The use of these three methods, oil burners, coal stokers, and gas producers, brings in quite a number of factors, many of which have great influence upon final efficiency. The two most important factors are dilution and the lowering of temperature by other agencies than excess air, as, for instance, by

steam and by radiation of heat from surfaces at high temperature.

A gas analysis obtained from a furnace using oil as fuel and a steam atomizer may show practically no dilution by excess air, and still the loss due to dilution may be exceedingly great. Steam is a very good carrier of heat, and the gas-analysis apparatus is incapable of showing its presence.

When an unsatisfactory burner is used or a good burner is improperly operated, excessive amounts of steam may be used for atomization. In certain furnaces, moisture in the waste gas was determined by its absorption with phosphorus pentoxide and it was found that the amounts were 2.02, 3.53, and 1.49 lb. of steam per pound of oil. These furnaces, three in number, were operated with a terminal temperature of 1800 deg. fahr. and the following data apply:

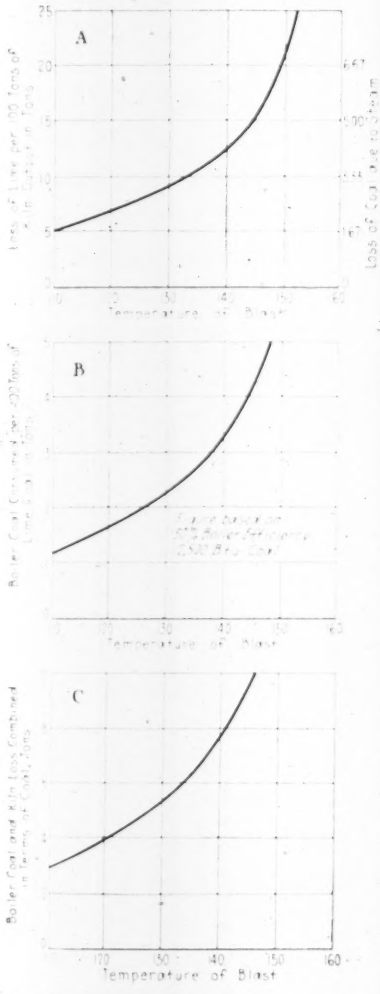

FIG. 6 EFFECT OF VARIOUS AMOUNTS OF STEAM IN GAS PRODUCER ON LOSS OF EFFICIENCY AND CAPACITY OF LIME OR CEMENT KILN

a If oil is burned with no steam and just the right amount of air, 61.8 per cent of the heat is available in the process if it is not lost by radiation.

b If oil is burned with just the right amount of air and one pound of steam per pound of oil, 56 per cent of the heat is available for the process in an ideally insulated furnace. The loss over *a* due to steam is 9.36 per cent of fuel.

c If oil is burned with the theoretical amount of air and two pounds of steam per pound of oil, 50.8 per cent of heat is available and the fuel loss due to steam is 17.8 per cent.

d If two pounds of steam are used per pound of oil and 50 per cent excess air with no loss due to radiation, the available amount of heat becomes only 35 per cent, with 26.8 per cent wasted.

e In actual practice the amount of heat lost is even greater, the increase being due mainly to radiation. Only 20 per cent of heat is actually used in the process and 41.8 per cent lost, the remainder, 38.2 per cent, being heat normally at low temperature.

However, the loss due to the use of steam is not all, it must be remembered that coal is also needed for the boiler, and that the boiler will represent increased investment and attention.

The chief argument advanced for the use of steam is that it tempers the flame and reduces wear of refractories. While this is true under certain conditions, the reverse may be true under others, and in any case the same results may be accomplished by other means such as recirculation of hot gas.

With gas producers, the same arguments apply as do to steam. Much of the steam that enters the producer is not decomposed into hydrogen, and so becomes a diluting agent with no useful purpose whatsoever. The portion that is decomposed often causes harm due to the fact that hydrogen is not a desirable fuel for industrial furnaces of the ordinary kind. Its combustion is too rapid, producing sharp and short flame of low radiant quality. Carbon monoxide is by far to be preferred. Both the steam decomposed and that undecomposed are carriers of heat from the furnace. It often is possible to substitute waste gas containing CO_2 from the furnace as an endothermic agent to be used in the producer. When this is not possible, the smallest amount should be used. Fig. 6 shows graphically what effect various amounts of steam used in the producer have on the loss of efficiency and capacity of a lime or cement kiln. For a producer-blast temperature of 145 deg. fahr., the loss is about twice as great as for a temperature of 130 deg. fahr., the difference being about 5 tons of coal per day or a heat loss of about 15 per cent in fuel and an additional loss due to lower production from equipment of high cost.

A good gas producer, which does not necessarily mean an automatic or a very expensive gas producer, when properly operated is quite regular in its supply of gas of constant quantity and quality. The objection to producers is the heat loss due to radiation. Any heat lost from the gas producer or gas flues of an installation with a high-temperature working level is very harmful. One must remember that the heat so lost is that which would have done useful work in the furnace. To get a true measure of radiation loss, the heat so lost must not be compared with the total heat in the fuel but rather with the heat used in the process. If the efficiency of a furnace is 25 per cent and radiation from producer, flues, and walls enclosing the high-temperature portion of the furnace is 15 per cent, then a reduction of this loss to 10 per cent would increase the furnace efficiency to 30 per cent and the saving would be 16.7 per cent in fuel. When figuring insulation one should not say that he will save so many heat units, but rather that he will make so many more heat units available in the process.

With oil and individually applied gas producers as well as stokers this radiation loss is greatly reduced, and to determine what really is most desirable, conditions must be carefully weighed. It is safe to say that in practically all cases direct, plain-grate coal firing is unsatisfactory and wasteful, if for no other reason than the smoke it creates should not be permitted.

The discussion of the problems encountered cannot be undertaken to any great extent in this paper. Naturally what is desired is to have the lowest possible temperature difference between the product and the kiln gases leaving the furnaces, and when a full muffle is used a material of high conductivity and of the greatest thinness consistent with required strength is desired. The muffle must be properly proportioned not only so as to accommodate the material but also to assure sufficient heat-radiating area for the transference of heat to the product. In furnaces radiant heat plays as great a role as heat transferred by convection, often even greater. A rotary lime or cement kiln is, in the main, a radiant-heat apparatus reflecting heat from flame to the product.

Full muffles are not desirable when cleanliness is not of great importance. Semi-muffles admitting the gases at the crown are preferable. Through this method the arch of the muffle is heated to a higher temperature than it could be if the heat had to pass through the arch, and thus a lower waste-gas temperature is assured. This method, however, puts the muffle under the chimney draft, and if the muffle door leaks, or if it is opened, air enters and cools the inside of the muffle. Any heat loss at this point where heat is applied is much more harmful than at any other point. Not only are the inner walls of the muffle cooled, but the heated product as well. Due to this care should be taken that muffles have tightly fitting doors and that they are operated as much as possible on balanced draft.

In discussion of Mr. Azbe's paper, Theodore B. J. Merkt wrote that in certain processes, particularly those where furnace atmospheres and accuracy of flame length and temperature were important, he had found the cleaning of the air required for combustion to be extremely important. In a certain case where impurities in city gas were said to be causing trouble, it was found that such was not the case. In another operation, the ease of changing from a reducing to an oxidizing atmosphere practically momentarily had perfected an operation which had always been more or less fitful.

In the control of fuels, the two matters often overlooked were the necessity for speed in attaining furnace temperatures, and the ability to vary at will and within narrow limits the atmospheres required in heat processes.

A fuel which could readily adapt itself to the above-mentioned conditions was one which must always command attention.

Burning Mid-Western Coals

While Each Has Its Own Peculiarities and Must Be Burned Accordingly, Any One of Them Can Be Burned if Properly Handled on Proper Equipment

By E. L. McDONALD,[1] KANSAS CITY, MO.

THE Mid-West coals referred to in this paper are mined in Iowa, Missouri, Kansas, Arkansas, Oklahoma, and Illinois. As much has been said and written about Illinois coal, the present discussion is confined principally to the other coals. Steam coals only are considered.

The Coal Fields

The light-shaded portions of the map, Fig. 1, show the coal areas under consideration and the heavy-shaded portions, the more active mining districts.

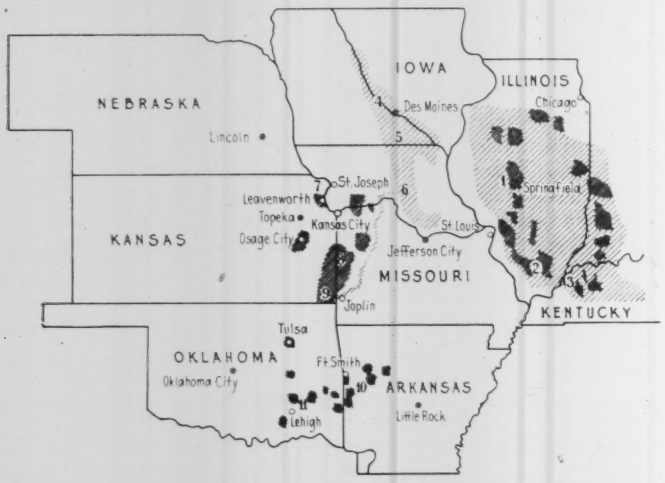

Fig. 1 Map of Mid-West Coal Areas
(Light shading shows coal areas; heavy shading shows more active mining districts.)

Illinois Coals. The greater portion of Illinois steam coal (which is all of bituminous rank) comes from the Peoria-Springfield district. The quality of the coal is poorest in the northern part of the state, increasing in value toward the south (with the exception of an area north of East St. Louis). The southern part of the state supplies most of the domestic coal, the slack from which is, of course, available for steam purposes.

Iowa Coals. The Brevier seam running down through Iowa along the Des Moines River valley, furnished bituminous coals suitable for steam purposes, but the quality and quantities available vary greatly throughout the state.

As a whole the coal is poorer than Springfield District Illinois or Missouri coal, although some fairly good coal is available from scattered spots.

Missouri Coals. The north Missouri fields are a continuation of the Brevier seam running down from Iowa. While the coal as a whole is of better quality than Iowa coal, it will not average as good as Springfield District Illinois coal. The Lower Weir Pittsburgh seam in the southwestern part of Missouri produces bituminous coal of a better quality, being equal to Springfield District Illinois coals, and is mined more extensively than the Brevier seam. There are several other seams of less importance in the state.

Kansas Coals. There are three distinct mining areas in Kansas, all producing bituminous coals; one in the vicinity of Atchison and Leavenworth producing a poor grade of coal about equal to Iowa coal; the second, a small district confined to Osage County producing a fairly good coal but in small quantities, and the third and most important area known generally as the Cherokee-Pittsburgh district, in the southeastern part of the state. This coal, as a whole, is equal to southern Illinois coal in heating value.

Oklahoma Coals. There are several mining districts in Oklahoma scattered over the central and eastern part of the state, from Tulsa down to Lehigh and east from these points. These districts produce coal of both bituminous and semi-anthracite rank, some of the coals being very high in coking qualities.

Arkansas Coals. There are six mining districts in Arkansas producing semi-anthracite and what is known locally as Arkansas anthracite, a coal approaching eastern semi-anthracite in analysis, but very fragile in structure, breaking down to slack very easily.

Methods of Mining

All of Illinois and practically all of Iowa coals come from shaft mines. Missouri and Kansas operate both shaft and strip pit mines. Oklahoma and Arkansas operate principally slope and shaft mines, with a few strip pit mines.

The methods used in shaft mining are quite generally known, but as strip pit mining is not so common, Fig. 2, showing the activities around a strip pit mine, will make the method better understood. This particular field contains a seam about 30 in. thick with an average overburden of 28 ft. Roughly, it is claimed that it is profitable to remove about 1 ft. of overburden for every inch of coal thickness, provided the overburden does not exceed 40 ft.

Table 1 gives the analyses of Mid-Western coals, and while true burning characteristics of the coals are not shown, the general nature and the variation that exists are clearly indicated. The analyses shown are not extremes in either direction, but have been picked out to represent average good and average poor coals from these fields. They all represent analyses made on coals "as received" at the power plant. The analyses shown should not be confused with samples taken from the coal seam, which always indicate a better quality.

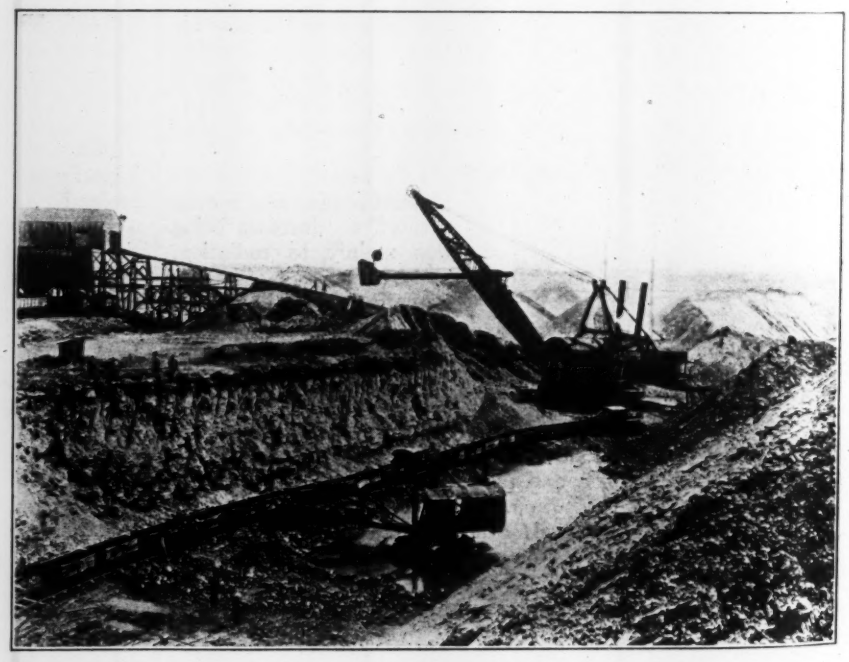

Fig. 2 Strip Pit Mining

[1] Efficiency Engineer, Kansas City Power and Light Co.

Contributed by the Fuels Division and presented at the Kansas City Meeting, Kansas City, Mo., April 4–6, 1927, of The American Society of Mechanical Engineers.

TABLE 1 ANALYSES OF COALS FROM MID-WESTERN FIELDS

State	County	No.	Grade	Analyses of coal as received: Moisture Per cent	Ash Per cent	Volatile Per cent	Fixed carbon Per cent	B.t.u.	B.t.u. Dry
Illinois	Sangamon & Macoupin	1	Good	14.20	11.89	35.16	38.75	10,350	12,070
			Poor	13.34	13.80	31.00	41.86	9,915	11,440
Illinois	Franklin	2	Good	13.93	9.27	34.80	42.00	11,190	13,001
			Poor	12.94	11.62	33.00	42.44	10,827	12,425
Iowa	Boone	4	Good	12.30	18.60	37.20	31.90	9,773	11,144
			Poor	13.20	27.20	28.50	31.10	7,503	8,640
Iowa	Appanoose	5	Good	20.80	24.12	28.00	27.08	8,741	11,020
			Poor	17.33	31.96	25.00	25.71	7,408	8,596
Missouri	Randolph	6	Good	13.25	19.09	30.33	37.37	9,492	10,941
			Poor	13.45	23.45	28.00	35.10	8,767	10,117
Missouri	Bates	8	Good	13.88	18.46	30.66	37.00	9,702	11,266
			Poor	13.55	23.08	28.62	34.80	8,680	10,030
Arkansas	Sebastian & Johnson	10	Good	3.50	11.57	14.93	70.00	12,850	13,316
			Poor	3.50	21.36	10.30	64.84	11,880	12,325
Kansas	Leavenworth	7	Good	10.69	24.38	27.60	37.33	9,465	10,620
			Poor	11.41	27.17	25.93	35.49	8,845	9,990
Kansas	Crawford & Cherokee	9	Good	6.80	13.86	27.57	51.87	12,187	13,050
			Poor	7.50	19.36	27.31	45.83	10,793	11,690
Oklahoma	Pittsburg	11	Good	6.76	6.78	15.25	71.17	12,817	13,737
			Poor	5.00	18.83	12.60	63.57	10,950	11,526

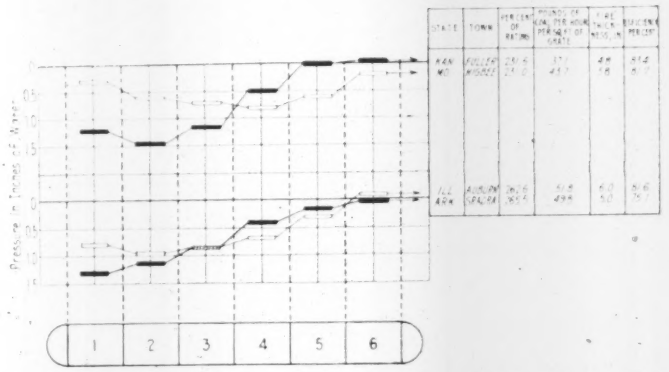

FIG. 3 ECONOMICAL STOKER-ZONE PRESSURES FOR VARIOUS MID-WEST COALS

An indication of the variation in quality of Mid-West coals is shown by the heating values tabulated, which vary from 7400 B.t.u. to 12,800 B.t.u. as received.

DRAFT CONDITIONS

While the burning of coal in pulverized form is undoubtedly the ideal method from a standpoint of thermal efficiency, at present there is more reliable information available on the burning of these coals on forced-draft stokers, hence this discussion will be confined to this type of equipment, choosing one of the forced-draft chain-grate stoker units installed in the Northeast Station of the Kansas City Power & Light Company at Kansas City, Missouri. This central station has available to it, through competitive freight rates, coals from all of these fields. The boiler unit consists of a Heine boiler, with 12,745 sq. ft. of heating surface, a superheater, economizer, and air preheater, and forced-draft Coxe stokers.

The forced-draft type of chain-grate stoker is well adapted to the burning of Mid-West coals. Its merit lies chiefly in the ability to control the air supplied to any portion of the fuel bed. The extent to which this control of air is desirable when burning different grades of Mid-West coal is best shown with the aid of a chart. Fig. 3 shows the economical or desirable air pressures for four coals with different burning characteristics. Note the different zone pressures when burning a Kansas and a Missouri coal, both developing the same percentage of boiler rating, and again, the contrast between Illinois and Arkansas coals when both are developing the same percentage of boiler rating.

The difference in air pressures required in the burning of these Mid-West coals is caused principally by rapidity of ignition, coal sizing, percentage of ash, and its fusion temperature.

The theoretical temperature required for the ignition of the fixed carbon in bituminous coal is about 770 deg. fahr. Ordinarily 1800 to 2200 deg. fahr. actually exists at the front of the arch. Coals slow to ignite demand less air in the front stoker zones.

Coals fine in size require thinner fuel beds and usually more pressure to force air through the fuel bed. Arkansas anthracite is in this class. Being fragile, it slacks easily, and $1^1/_4$-in. screenings will contain about 75 per cent through a $^1/_4$-in. screen, whereas Illinois $1^1/_4$-in. screenings will contain only about 30 per cent through a $^1/_4$-in. screen.

FUSION TEMPERATURE OF ASH

Coals with a low-fusing-temperature ash that tends to mat over the grate naturally require more air pressure to overcome this resistance. The fusion temperature of some of the lower-grade Mid-West coals will run as low as 1800 deg. fahr. The majority will range between 2000 and 2180 deg. fahr.

Ash fusing at a low temperature and during the early stages of combustion will completely embed carbon particles, thereby preventing air from coming in contact with them to complete combustion. While this occurs to some extent in the burning of any kind of coal, it is naturally more pronounced in most of the Mid-West coals with their high percentages of low-fusing ash.

The low-fusing ash, resulting in high ashpit losses, together with the high moisture and hydrogen content, resulting in unavoidable stack losses, are three reasons why efficiencies cannot be obtained with Mid-West coals equal to those obtained with some Eastern coals.

MOISTURE

Moisture plays a very important part in the burning of Mid-West coals on chain-grate stokers. The average moisture content of Missouri coal is 12 to 14 per cent, but coal is often received containing over 20 per cent moisture. With this high moisture, ignition and proper combustion are difficult. On the other hand, coal is received from fields, particularly Arkansas, with a moisture content too low for good firing conditions and moisture must be added to this coal to obtain a uniform fuel bed and to prevent the formation of holes and the carrying of finer particles up through the boiler and out the stack.

FIG. 4 SLAG ON BOILER TUBES AFTER NINE DAYS OF OPERATION AT 240 PER CENT OF RATING

CHARACTERISTICS OF BURNING

All of these Mid-West coals have their own peculiarities in burning. Most Missouri coals burn with a long, heavy flame and develop a furnace temperature of about 2700 deg. fahr. at normal rating. Kansas coals burn with somewhat shorter and clearer flame and develop about 2850 deg. fahr. furnace temperature at normal rating. Many of the Kansas coals are of a coking nature. Oklahoma coals can develop high furnace temperatures, and most of them are highly coking coals.

Arkansas anthracite burns with a short, transparent flame, practically the entire fuel bed being visible. Due to its fineness and light structure, millions of small incandescent carbon and ash particles are lifted from the fuel bed, some falling back on the rear of the stoker like snow and a great part traveling through the boiler passes in the form of red-hot sparks. This coal cannot be successfully burned on the natural-draft chain-grate stoker.

SLAGGING

The high ash, sulphur, and iron content of most Mid-West coals make slagging problems more acute than with most Eastern coals and ample cleaning facilities must be provided, not only in the form of soot blowers but rodding doors as well in order to permit knocking off the heavy slag deposits in the first pass of the boiler.

The extent to which a boiler will slag up with some Mid-West coals is shown in Fig. 4. This was taken from the rear of the stoker looking up into the first pass of the boiler, and shows conditions after nine days of operation at 200 per cent of rating when

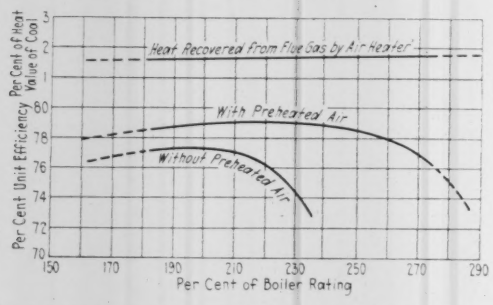
Per Cent of Heat Value of Coal
Heat Recovered from Flue Gas by Air Heater
With Preheated Air
Without Preheated Air
Per Cent Unit Efficiency
Per Cent of Boiler Rating

FIG. 5 COMPARATIVE EFFICIENCIES, WITH AND WITHOUT PREHEATED AIR. HUME MISSOURI COAL

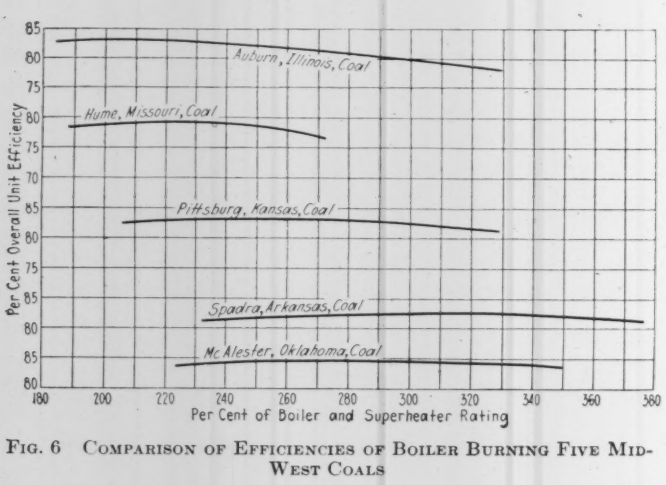
Auburn, Illinois, Coal
Hume, Missouri, Coal
Pittsburg, Kansas, Coal
Spadra, Arkansas, Coal
Mc Alester, Oklahoma, Coal
Per Cent Overall Unit Efficiency
Per Cent of Boiler and Superheater Rating

FIG. 6 COMPARISON OF EFFICIENCIES OF BOILER BURNING FIVE MID-WEST COALS

burning a certain Kansas coal. The gas passages are practically plugged solid; slag has been knocked down at the center to show the original opening.

Rodding doors have been used for several years where it is necessary to remove slag, but even with this provision, boilers must come down every 25 or 30 days for a general cleaning.

PREHEATED AIR

Bituminous coal is commonly referred to as a "free-burning coal;" as a whole this is correct, but with some of the Mid-West coals running up to 35 per cent ash and impurities, the expression "free burning" is a misnomer, in fact, on certain equipment it is often difficult to maintain ignition. The ignition of these low-grade coals has been greatly stimulated in the past few years by the application of preheated air for combustion. In the Northeast Power Station boiler units the air is heated to about 200 deg. fahr. and is forced through the fuel bed at that temperature. At this temperature there is no detrimental effect on the stoker or furnace lining; in some more recent plants in which air is preheated to 500 deg., some trouble has been experienced. The preheated air permits more rapid combustion with less excess air, and results in higher efficiencies.

The effect of preheated air on a certain Mid-West coal is shown by the curves of Fig. 5. These show the efficiencies and ratings derived from the same kind of coal when burned with and without preheated air. This of course is an extreme case, and all coals do not show such a pronounced gain. The average gain at normal ratings is about 3 per cent on the unit at the Northeast Power Station.

The top curve in Fig. 5 indicates the percentage gain due to heat units absorbed from the flue gas. From the difference in efficiencies it is evident that the gain by preheating air for combustion, particularly at higher ratings, is in excess of that accounted for in heat units absorbed from the flue gases.

The efficiency and capacity obtained with the average Mid-West coals are shown in Fig. 6, which shows the actual results obtained on tests of five representative coals from five of the states.

BOILER EFFICIENCIES

The tests were conducted on the boiler unit at the Northeast Power Station previously referred to, and, as will be seen, the unit efficiencies when burning all of the coals (except Missouri) averages about 82.5 per cent with boiler ratings running up to 380 per cent. Because of excessive slagging and fluxing of the ash and firebrick at high ratings, the units are normally operated at about 240 per cent of boiler rating.

In summing up the burning of Mid-West coals, it may be said that while each coal has its own peculiarities and must be burned accordingly to obtain efficient results, any one of them can all be burned if properly handled on the proper equipment.

Fuel of Major Importance in Life of Refractories

PROGRESS in the development of furnaces depends as much upon the development of refractories as does the advancement in the automobile industry depend upon the properties shown by alloy steels. Experience has shown that the type of fuel is of major importance in the life of refractories. It is found that in a general way a certain type of refractory stands up better in an oil-fired furnace than in one fired by gas. An explanation of this cannot be offered, although an important factor is that small combustion tunnels are used with gas burners. These tunnels being made of the refractory are subjected to the high temperature of the ignited gas. In the case of the oil burner, combustion takes place more in the furnace and produces a glaze on the surface of the refractories, which seems to protect them, giving longer life. It is desirable to reduce the flame of the combustion chambers to increase efficiency, so that combustion engineers are concerned with the development of more suitable refractories.

It has been shown that it is possible to develop as high as 550,000 B.t.u. in a cubic foot of combustion space in one hour. This is equivalent to burning more than 1000 cu. ft. of city gas in this volume for this period. Manufacturers of refractories argue that combustion chambers should be made larger, reducing the severity of furnace conditions, and it is admitted that such a design would allow the use of refractories which are of the least expensive type, but such a practice would not be advancement. With more efficient furnace designs, a higher-grade and higher-priced refractory can be used.

Considerable use is made of silicon carbide, but this material requires reducing atmosphere often at comparatively low temperatures. Its high thermal conductivity is often of great value, especially in the case of muffle furnaces, but it is not always feasible to operate these with a reducing atmosphere.

Furnaces employing silicon carbide give better service when fired with oil burners. It is desired, therefore, to obtain a refractory which will exhibit the properties of silicon carbide at temperatures as high as 2500 deg. in oxidizing atmosphere.

At the present time the thermal efficiency of brass- and copper-melting crucible furnaces is about 10 per cent. This is not sufficiently high for industrial efficiencies, and the solution of the problem lies in obtaining refractory material which is more suitable. Some time ago a furnace of high efficiency was constructed, but as a result of a few hours' operation the refractories in it were melted.

Advancement in the future no doubt will be along the lines of indirect gas or oil-fired furnaces. This means that the combustion chambers will be in the nature of small ducts made of refractories in which high temperature will be maintained.—Leo W. Briggs in a paper presented before the American Refractories Institute, Atlantic City, N. J., May 18, 1927, and published in the *Iron Trade Review*, July 21, 1927, vol. 81, no. 3, p. 141.

Refractories Service Conditions in a Furnace Burning Pittsburgh Coal on Underfeed Stokers[1]

Progress Report of the A.S.M.E. Special Research Committee on Boiler-Furnace Refractories

By R. A. SHERMAN[2] AND W. E. RICE,[3] PITTSBURGH, PA.

THIS report presents data which pertain to furnace conditions that affect the life of refractories in furnaces burning coals from the Pittsburgh No. 8 bed on underfeed stokers. The investigation, which was conducted at the Lowellville, Ohio, station of the Pennsylvania-Ohio Power and Light Company, was a part of the study of boiler-furnace refractories conducted by the Bureau of Mines in coöperation with the Special Research Committee on Boiler-Furnace Refractories of The American Society of Mechanical Engineers.

The average life of the furnace walls at this station was reported to be approximately two years. The principal factors, resulting in this relatively long life, were the low average rates of steaming with infrequent periods of high rates; the use of coal whose ash did not erode the refractories; and the use of air-cooled blocks in the side and front walls from the grate to the top of the fuel bed.

Objects of Investigation

The objects of the investigation at this station were:

1 To obtain data on furnace conditions when burning Pittsburgh coal on an underfeed stoker.

2 To compare the furnace conditions and their reaction on the same refractories when burning a high- and a low-sulphur coal.

3 To compare the data obtained with the high-sulphur coal with those previously found for the same coal when used in a furnace equipped with chain grates.

Scope of Investigation

Refractories temperatures and furnace-gas velocities were measured only when burning the usual station coal. Furnace-gas temperature and composition, sulphur content of the furnace gases, and the amount and composition of the solid materials carried in the furnace gases were studied when burning the two types of coal.

Particulars of Furnace

The furnace in which conditions were investigated was under a longitudinal-drum, vertical-header boiler having 6000 sq. ft. of heating surface, fired by a 7-retort underfeed stoker which had a projected grate area of 121 sq. ft. The volume of the furnace was 1014 cu. ft.

The stoker was fitted with low, inclined side-wall tuyeres which were retained for the tests. The air-cooled blocks were replaced by standard 9-in. bricks in order to make conditions more nearly comparable to those in the investigation of conditions when burning Pittsburgh coal on chain grates, where air was admitted only through the grates.

TABLE 1 PERCENTAGE ANALYSES OF COALS USED IN TESTS

Proximate Analysis	Low-sulphur coal	High-sulphur coal
Volatile matter	32.2	37.8
Fixed carbon	58.1	51.1
Ash	9.7	11.1
	100.0	100.0
Ultimate Analysis		
Hydrogen	5.4	5.0
Carbon	77.1	72.5
Nitrogen	1.5	1.3
Oxygen	5.2	7.0
Sulphur	1.1	3.1
Ash	9.7	11.1
	100.0	100.0
Calorific value, B.t.u. per lb.	13,770	13,000
Softening-temperature range, deg. fahr	2560–2740	2060–2275
Softening-interval range, deg. fahr	100–160	70–300
Fluid-interval range, deg. fahr	60–130	60–130

Figs. 1 and 2 are sections of the furnace which show the holes for measuring the temperatures and sampling the furnace gases, and the bricks in which temperatures were measured in the front and side walls. Fig. 13-A also shows the holes and the bricks.

Coals Burned

The coal burned regularly at the station came from Westmoreland, Washington, and Fayette counties, Pennsylvania. It is designated in the report as low-sulphur coal. The special coal used came from Belmont County, Ohio, and is designated as high-sulphur coal. Analyses of composite samples of these coals on a moisture-free basis and the range of the softening temperatures of their ash are given in Table 1.

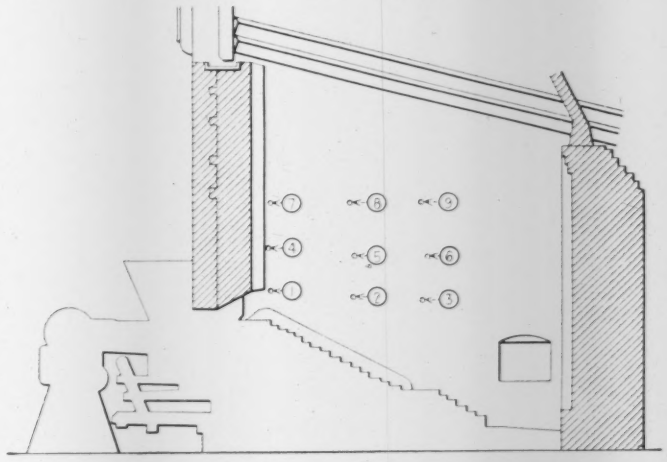

FIG. 1 SECTION OF FURNACE SHOWING HOLES THROUGH WHICH GAS SAMPLES WERE DRAWN AND TEMPERATURES AND GAS VELOCITIES WERE MEASURED

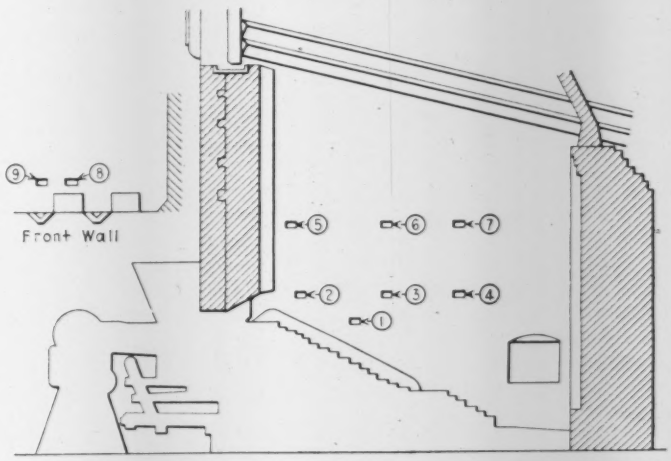

FIG. 2 SECTION OF FURNACE SHOWING BRICKS IN WHICH TEMPERATURES WERE MEASURED

Refractories Temperatures

Temperatures were measured over several days of normal operation in 7 bricks in the side wall and 2 bricks in the front wall of the furnace. Figs. 2 and 13 show the positions of these bricks. Thermocouples placed at 1/2, 1, 3, and 6 in. from the hot face of the bricks were designated A, B, C, and D, respectively. Only the bricks at positions 1, 3, 8, and 9 had thermocouples at the A- or

[1] Published with the approval of Director, U. S. Bureau of Mines.

[2] Associate Fuel Engineer, Pittsburgh Experiment Station, Bureau of Mines. Assoc-Mem. A.S.M.E.

[3] Assistant Fuel Engineer, Pittsburgh Experiment Station.

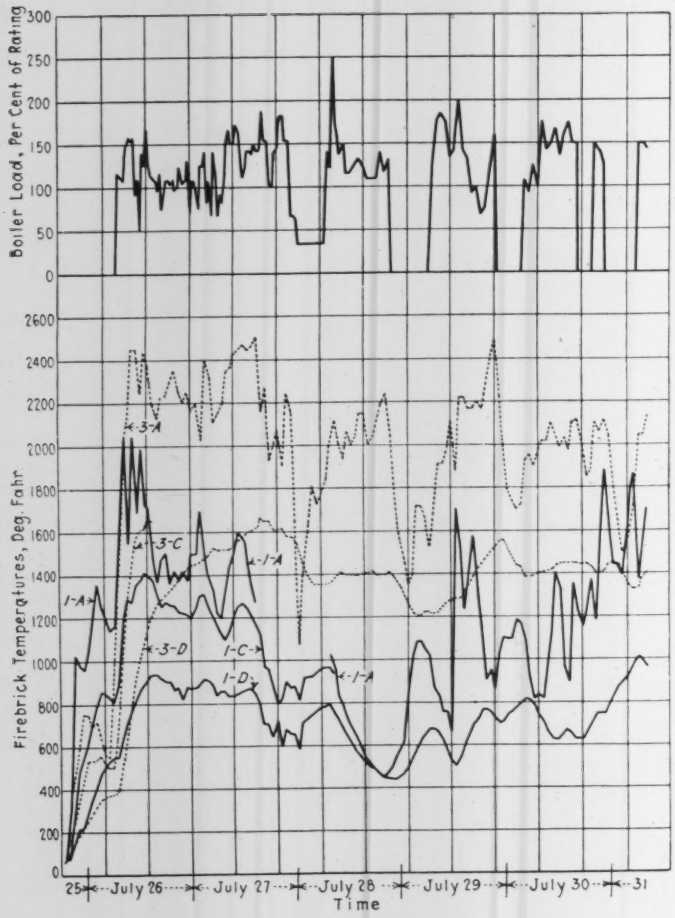

FIG. 3 TIME-TEMPERATURE CURVES, SIDE WALL

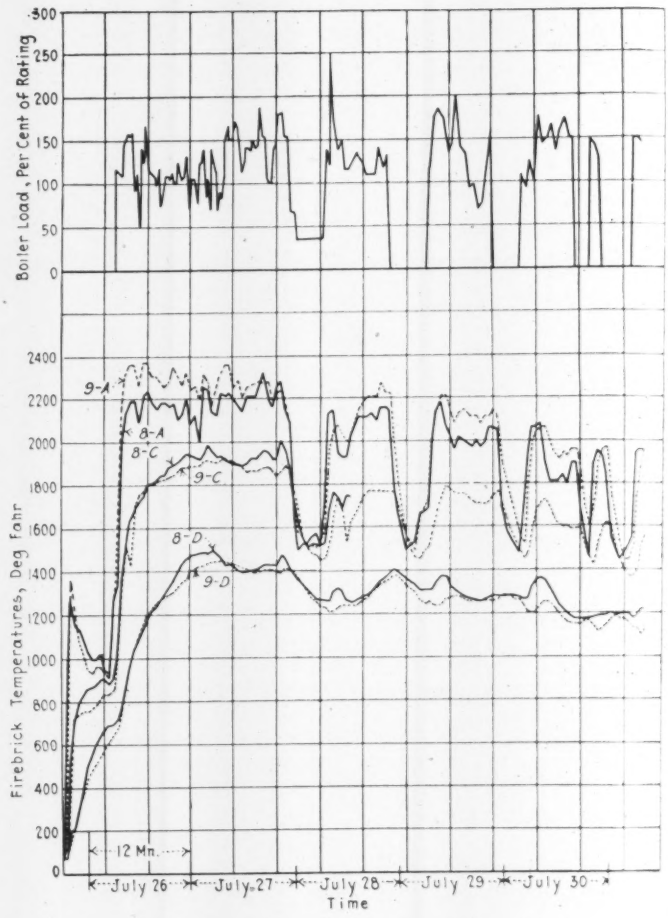

FIG. 4 TIME-TEMPERATURE CURVES, FRONT WALL

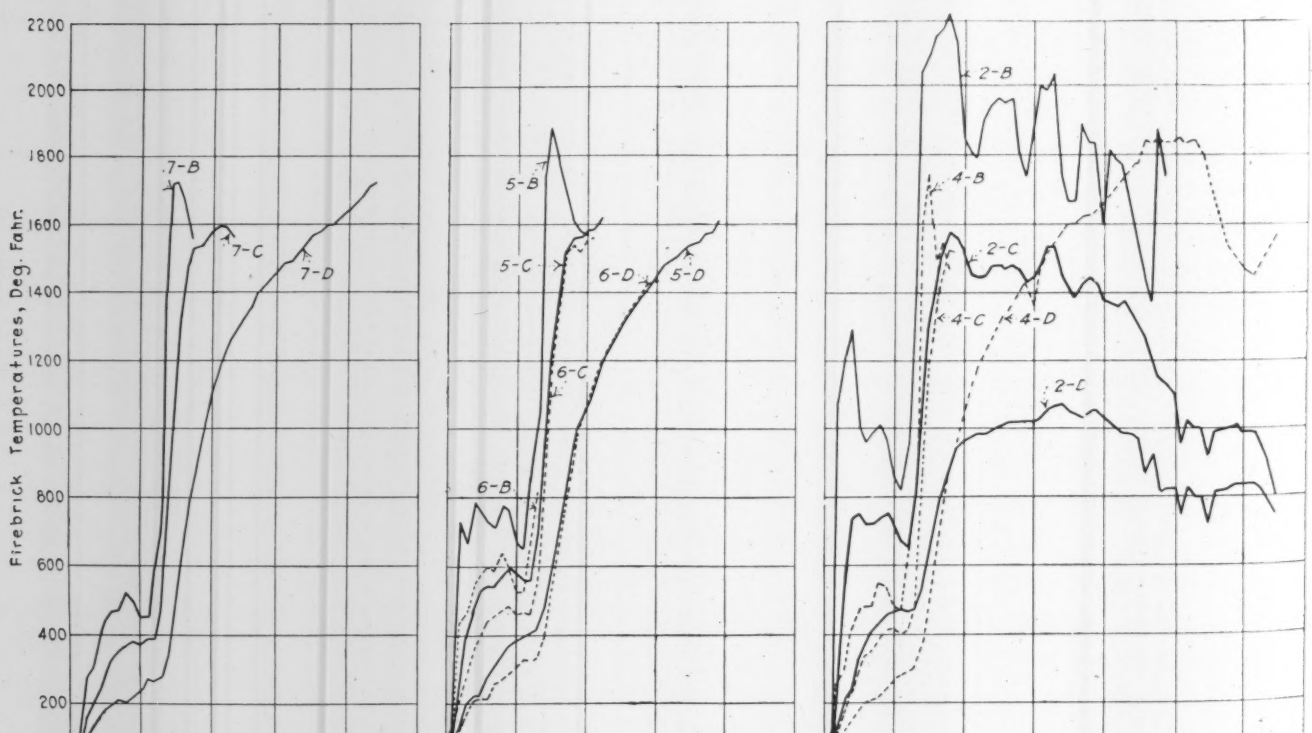

FIG. 5 TIME-TEMPERATURE CURVES, SIDE WALL

1/2-in. position. The A-couples were of platinum and platinum-rhodium, while the others were of base metal.

Many of the base-metal couples ceased to give readings during the second day of the test. This was of interest as the temperatures at the time were too low to cause failure by complete oxidation of the wires. It is considered probable that their failure was due to breakage of the partly oxidized wires by movement of the wall.

Fig. 3 gives the temperatures in bricks Nos. 1 and 3 plotted against time from the lighting of the fires. The load on the boiler in percentage of rating is plotted in the upper part of the figure. There was a preliminary period of 12 hours during which a small fire was carried on the stoker to heat the setting gradually, the boiler not steaming during that time, followed by approximately 5 days of normal operation.

Brick No. 1 was 10 in. above the inclined side-wall tuyere and was consequently always below the surface of the fuel bed. Brick No. 3 was 24 in. above the tuyeres but was still generally below the surface of the fuel bed. The temperatures at 1/2 in. from the surface of the bricks, couples 1-A and 3-A, increased together from the time the boiler was put on the line until a temperature of 2000 deg. fahr. was attained, when the temperature of 1-A fell while that of 3-A continued to rise. The temperatures in brick No. 1 continued to fall except for short rises during the following two days, until at the close of the 28th the temperature at 1/2 in. from the surface was less than 500 deg. This decrease in temperature was obviously due to the insulating effect of the increasing accumulation of slag on the walls. About midnight of the 28th the slag was sliced from the walls and the temperature rose sharply but again fell up to noon of the 29th, when a more thorough cleaning of the wall was effected and a sharper rise took place. The effects

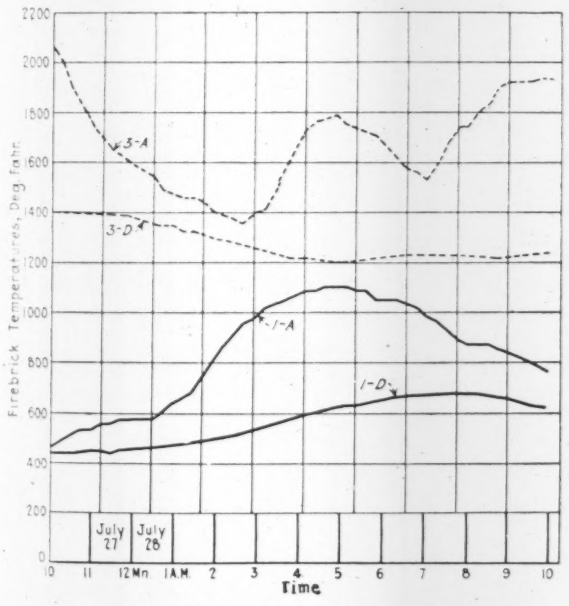

FIG. 6 TIME-TEMPERATURE CURVES, SIDE WALL

of other slicings may be seen later in the curve. Slag also accumulated on brick No. 3, resulting in lower temperatures and subsequent rise on slicing, but not to the extent that it did in the lower part of the fuel bed.

Fig. 4 gives similar curves for the temperatures in bricks Nos. 8 and 9, which were in the front wall over a retort and a row of tuyeres, respectively. At 1/2 in. from the surface the temperature of the brick over the tuyeres was generally higher than that of the one over the retort, but at 3 or 6 in. from the surface the reverse was true. The steeper gradient through the brick over the tuyeres may have been due to leakage of air past this brick from the duct which had formerly led air to the air-cooled blocks. It will be noted that on successive days the temperatures were lower than on the previous day. This was caused, as has been pointed out above, by gradual accumulation of slag.

Fig. 5 gives the initial rise of temperature for bricks Nos. 5, 6, and 7, and the temperature curves for 60 hours for bricks Nos. 2 and 4.

The effect of the slow heating-up period of 12 hours on the temperature rise of the walls is interesting to note. The temperature at 6 in. from the hot face of the bricks Nos. 8 and 9, in the front wall at the end of the period was approximately 700 deg.; of brick No. 1, below the surface of the fuel bed, about 600 deg.; and of the other bricks, not over 400 deg. These temperatures rose rapidly when the boiler was put on the line. The heating period should have been considerably prolonged if it were desired to raise the wall temperatures slowly to those obtaining at normal steaming rates.

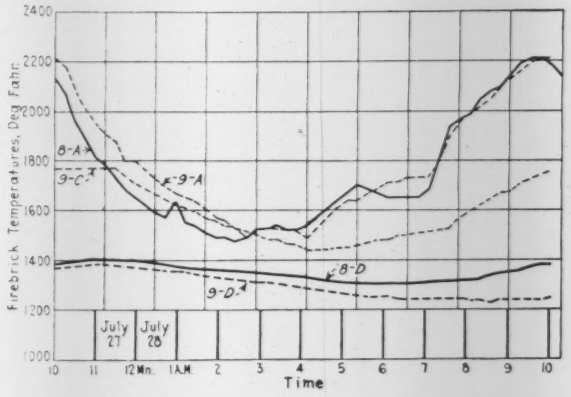

FIG. 7 TIME-TEMPERATURE CURVES, FRONT WALL

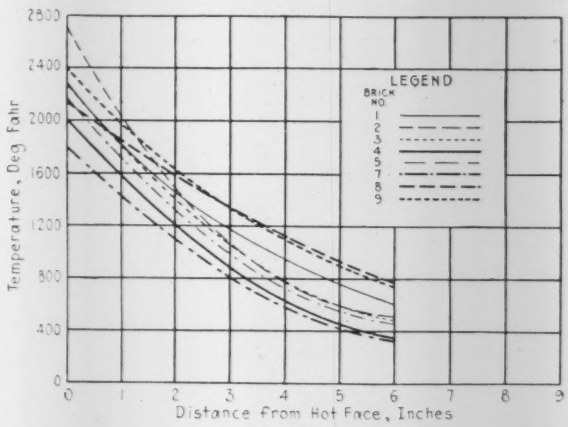

FIG. 8 TEMPERATURE GRADIENTS THROUGH BRICKS, UNDERFEED-STOKER-FIRED FURNACE

It is unfortunate that no data are available on the effects of rapid heating of walls or on the permissible or advisable rates of heating through the various temperature ranges.

Figs. 6 and 7 present the temperatures in bricks Nos. 1, 3, 8, and 9 over the banking period of July 28 and 29 on an extended time scale, readings being plotted every 15 minutes. These figures present more clearly the rate of change of temperature on banking and subsequent placing the boiler in service.

Fig. 8 gives temperature gradients through the bricks in the various positions drawn from the temperatures at 14 hours from the time of lighting the fire. At this time the temperatures were rapidly increasing, but the curves as extended to the face of the bricks from the 1/2-in. or 1-in. position give an indication of the temperature distribution on the furnace walls. The highest temperature was in brick No. 2, which was at the front of the side wall about the top of the fuel bed. The lowest was in brick No. 7, five feet above the extension grates.

FURNACE-GAS TEMPERATURE AND COMPOSITION

Fig. 9 gives the temperature and composition of the gases at the side wall of the furnace at the nine positions when burning the two types of coal at three boiler ratings of approximately 120, 150, and 180 per cent. Positions 1, 2, and 3, on the lower level, were intended to be just above the fuel bed, but as this was carried heavier than was anticipated, positions 1 and 2 were below the surface at all times and position 3 was below frequently.

The temperatures varied over a wide range; the range was greatest

on the lower level where the temperatures measured were those of the gases passing between the fuel and the wall. The highest temperatures on each level were generally at the middle position, 2, 5, and 8, or about half-way between the front wall and the end of the extension grates. The maximum temperature occurred at position 2; for the low-sulphur coal it was approximately 2600 deg. fahr., and for the high-sulphur coal, 2750 deg. fahr.

The combustible contents of the gases were, in general, greatest at positions 2, 5, and 8, as were the temperatures. With the low-sulphur coal the maximum combustible content of the gases was at position 2, decreasing as the gases rose in the furnace. With the high-sulphur coal the carbon monoxide and hydrogen contents were greater at position 5 than at position 2, but decreased again at position 8.

The combustible content of the gases was greater when burning the high-sulphur coal than when burning the low-sulphur coal. It was greater with the high-sulphur coal at 120 than at 150 per cent of rating. No samples were taken at 180 per cent with this coal. There was no carbon monoxide or hydrogen in the gases at 180 per cent of rating with the low-sulphur coal.

Fig. 10 gives the composition of the gases along the front wall of the furnace at positions 1 and 4, and the temperatures at positions 4 and 7. Measurements and samples were taken at 10-in. intervals from 14 in. from the side wall, which was above

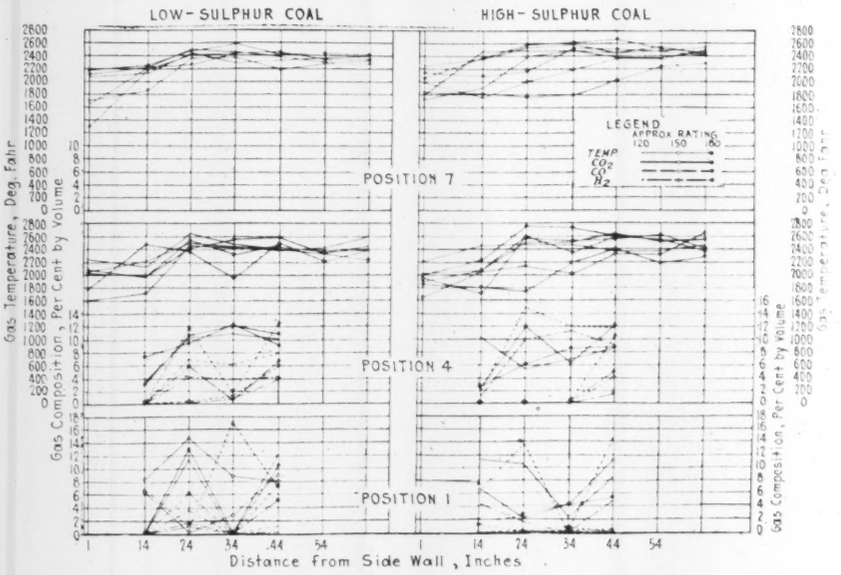

FIG. 10 GAS COMPOSITION AND TEMPERATURE ACROSS FURNACE

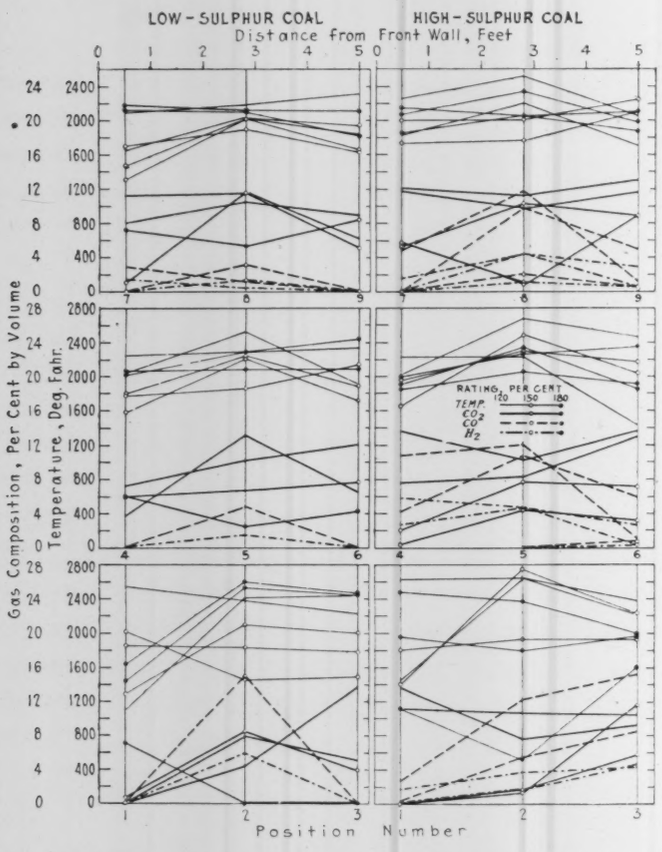

FIG. 9 GAS TEMPERATURE AND COMPOSITION AT THE SIDE WALL, UNDERFEED-STOKER-FIRED FURNACE

the first retort, and successive 10-in. intervals being alternately above tuyeres and retorts.

The temperatures increased from the side wall to the 24-in. position and were then somewhat more uniform across the furnace. As with the temperatures at the side wall, the maximum temperature, 2750 deg. fahr., was found when burning the high-sulphur coal. The temperatures were less uniform across the furnace with the latter than with the low-sulphur coal.

The composition of the gases varied greatly along the wall. The samples at position 1 were taken directly from within the fuel bed. Two sets of samples with the low-sulphur coal at 120 and 180 per cent of rating were of interest in their regular variation in passing from retort to tuyere. The CO_2 content was zero over the retort, about 11 and 13 per cent, respectively, over the tuyeres, zero over the next retort, and 12 and 10.5 per cent over the succeeding tuyeres. The maximum carbon monoxide content was 17 per cent above a retort at 150 per cent of rating with the low-sulphur coal.

There was apparently no regular variation in the combustible content of the gases with the rating when burning the low-sulphur coal, but this was greatest at the lowest ratings with the high-sulphur coal.

SULPHUR CONTENT OF GASES

The sulphur content of the furnace gases was determined at the three boiler ratings at positions 1 to 6, inclusive, for both the low-sulphur and high-sulphur coals. A total of 44 samples was taken and analyzed.

The results obtained varied widely, ranging from 0.004 to 0.046 and from 0.016 to 0.114 gram of SO_2 per cu. ft. for the low-sulphur and high-sulphur coals, respectively. Expressed in percentage of volume, the maximum was 0.07 per cent with the low-sulphur and 0.17 per cent with the high-sulphur coal.

The SO_2 content expressed in either of these ways is affected by the CO_2 content—that is, by dilution. The results were recalculated to the weight of SO_2 per unit weight of carbon present in the gas. This eliminates the effect of the variable excess air and gives more uniform values. The average of this value was 0.013 for the low-sulphur and 0.048 for the high-sulphur coal.

The weight of SO_2 per gram of carbon in the gas if all the sulphur of the coal were present in the gas would be 0.031 for the low-sulphur and 0.095 gram for the high-sulphur coal.

It is seen from the foregoing that approximately one-half of the total sulphur of the coal was in the gases at the points of sampling.

FURNACE-GAS VELOCITIES

Figs. 11 and 12 show the velocities of the furnace gases at the side wall and across the furnace when burning low-sulphur coal. They vary greatly, with no particular relation to the rating or position. The velocity was frequently zero, and the highest measured was 45 ft. per sec.

Such variations in velocity are to be expected in a furnace fired by an underfeed stoker where the velocity of the gases at a given rate of air supply is determined by the size of the openings between pieces of coke in the fuel bed. The size of the openings constantly changed with movements of the fuel bed, consequently the velocity of the gases varied.

SLAG QUANTITIES

Table 2 gives the results of the determinations of the quantity of non-combustible material carried in the gases passing the wall at position 6 at several different ratings for the two coals. The weight of material per 100 cu. ft. when burning the low-sulphur coal varied from 0.24 to 1.30 grams, with an average of 0.77 gram; and when burning the high-sulphur coal the weight varied from 0.15 to 0.73 gram, with an average of 0.47 gram.

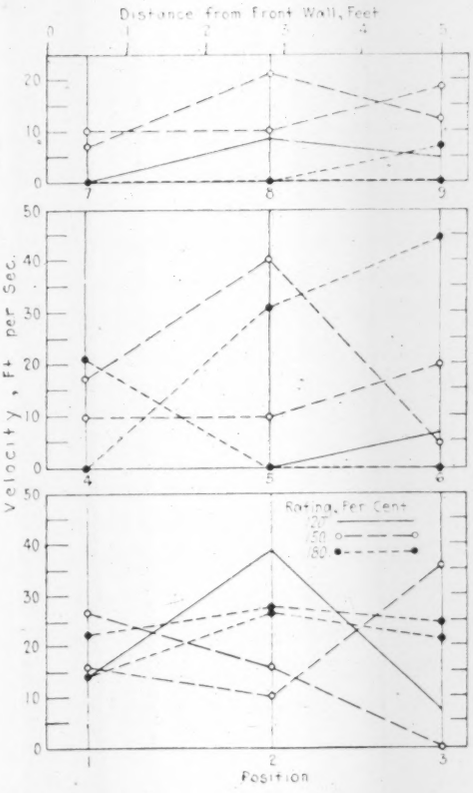

FIG. 11 VELOCITIES OF GASES AT SIDE WALL, UNDERFEED STOKER—LOW-SULPHUR COAL

Expressed as a percentage of the total ash fired to the furnace in the coal, the values ranged from 0.9 to 5.0 for the low-sulphur coal and from 0.5 to 2.4 for the high-sulphur coal. The averages were 2.9 and 1.5 per cent, respectively, for the low- and high-sulphur coals.

These values for the amount of ash carried up in the furnace gases when burning the coal on underfeed stokers have been approximately confirmed by the statement of the operators of this station that the ash removed from the combustion chambers, breeching, and stacks over a period of one month was 4.5 per cent of the ash fired.

TABLE 2 QUANTITY OF SLAG CARRIED IN FURNACE GASES

Sample No.	Per cent of boiler rating	Weight of material, grams per 100 cu. ft.	Material, percentage of ash fired to furnace
	Low-Sulphur Coal		
9	133	0.24	0.9
8	150	1.30	5.0
2	150	0.93	3.6
5	183	0.53	2.0
6	180	0.83	3.2
Average		0.77	2.9
	High-Sulphur Coal		
17	125	0.15	0.5
18	150	0.64	2.1
13	150	0.73	2.4
10	166	0.25	0.8
11	192	0.37	1.2
12	192	0.68	2.2
Average		0.47	1.5

REFRACTORIES SERVICE AND COAL ASH AND SLAG COMPOSITION

Before the tests were started, the furnace was relined with new bricks to the extent shown at A and B in Fig. 13. These bricks were the standard brand used at the station. The manufacturers stated that they were made from clays from Clarion County, Pennsylvania, by the dry-press method.

The boiler was in service burning the low-sulphur coal from July 25 to August 13, inclusive, a period of 18½ days. The daily variations in load were similar to those shown in the temperature curves of Fig. 3.

Samples were taken of the coal, ash, and refuse from the ashpit, and slags from various parts of the furnace. Table 3 gives the composition of these samples. The first line of this table gives the composition of a composite sample of the low-sulphur coal ash. The Fe_2O_3 content of the ash and also the total flux—that is, the constituents other than silica and alumina—were relatively low and the softening temperature high.

In Fig. 13 at C and D are shown the walls at the end of this period before any slag or clinker had been removed therefrom. That on the side wall represented an accumulation of perhaps 24 hours, as the walls were sliced each night. That on the front wall had accumulated over the entire period, as no door for slicing was provided in the side wall.

The slag which had been deposited on the upper part of the walls was of the honeycomb type. It consisted of a mixture of fused glassy material and apparently unfused or only sintered grains of slag. It adhered rather strongly to the walls, but there were no signs of erosion.

Samples 33, 34, 35, and 37, whose analyses are given in Table 3, were taken from various parts of the walls. There are no great differences among them. Sample 34, from the lower bridge wall, was largely fused material, while sample 35, from the upper bridge wall, was only sintered. The samples differed in composition by

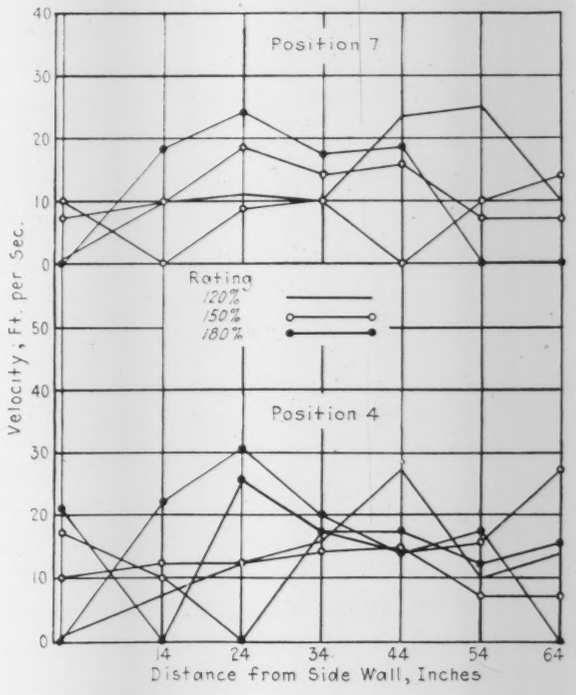

FIG. 12 GAS VELOCITIES ACROSS FURNACE, UNDERFEED-STOKER FURNACE—LOW-SULPHUR COAL

approximately 2.5 per cent in their total fluxes. The softening temperature of the fused material was lower than that of the unfused by 120 deg., which may be accounted for more by the higher temperature to which it had been subjected than by the difference in composition. After a heterogeneous material such as a coal ash has once been fused and the constituents more or less united in a slag, the softening temperature will ordinarily be lower than before such heat treatment.

Sample 36 was of pieces picked from the slag along the side wall which were white, flint-like material and had apparently been little affected by the treatment they had undergone. This approximates a clay in composition with only 7.6 per cent flux, and with a softening temperature of 2790 deg.

It will be noted that the Fe_2O_3 content of all these samples ex-

TABLE 3 COMPOSITION OF COAL-ASH AND SLAG SAMPLES

Coal	Sample No.	Description of sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O** and Na_2O	S as SO_3	SiO_2/Al_2O_3 ratio	Softening temperature	Softening interval	Fluid interval
	13, 14, 38, 39 and 40	Coal ash (composite)	55.9	29.7	8.3	2.0	0.6	2.3 - 1.2		1.88	2560 to 2740	100 to 160	60 to 130
	41	Ash and refuse	57.9	30.5	7.9	1.3	0.5	1.8	0.1	1.90	...	...	...
	32	Dust from soot chamber	50.1	29.9	13.9	3.8	1.0	0.0	1.5	1.68	2340	130	250
	33	Slag from above tuyeres on front wall	51.2	30.1	13.6	3.3	0.3	1.5	0.0	1.70	2150	70	240
	34	Slag from lower bridge wall	52.7	31.8	10.9	2.9	0.2	1.4	0.1	1.66	2250	140	410
	35	Slag from upper bridge wall	50.8	31.1	12.1	3.3	0.4	2.2	0.1	1.63	2370	180	170
Low-sulphur	36	White pieces of slag from lower side wall	61.6	30.8	4.4	1.2	0.3	1.6	0.1	2.0	2790	220	+200
	37	Slag from upper side wall	51.2	32.3	11.6	3.2	0.5	1.2	0.0	1.58	2270	170	300
	2*	Slag from gases Pos. 6 150% rating	46.9	28.9	10.4	2.4	0.1	...	0.9	1.62	...	...	...
	4*	Slag from gases Pos. 4 150% rating	44.6	29.7	12.0	0.3	0.1	...	0.9	1.50	...	...	...
	5*	Slag from gases Pos. 6 180% rating	44.9	31.1	8.9	2.3	0.0	...	0.5	1.44	...	...	...
	6*	Slag from gases Pos. 6 180% rating	48.6	32.7	9.0	2.1	0.1	...	0.3	1.49	...	...	...
	55, 56, 57, 58, 71, and 72	Coal ash (composite)	45.6	22.1	26.3	1.7	0.8	2.2	1.3	2.06	2100	130	190
	73	Ash and refuse	48.0	23.3	23.3	1.8	1.0	2.0	0.6	2.06	...	...	...
	74	Dust from soot chamber	39.5	21.9	32.7	2.8	0.7	1.3	1.1	1.8	2040	100	200
	75	Slag from boiler tubes Outer portion	40.3	22.6	33.7	1.9	0.5	1.0	0.2	1.78	...	...	...
High-sulphur	76	Inner portion						5.9					
	77*	Slag from gases Pos. 6 165% rating	35.0	20.1	37.6	1.1	0.6	...	0.0	1.74	...	...	...
	78*	Slag from gases Pos. 6 150% rating	40.3	21.1	31.6	1.5	0.6	...	0.4	1.91	...	...	...
	83*	Slag from gases Pos. 6 150% rating	42.8	22.7	28.8	1.5	0.7	...	0.0	1.88	...	...	...

*Approximate composition.
** By difference

cept the last mentioned was about 50 per cent greater than that of the original coal ash.

Samples 2, 4, 5, and 6 were taken from the furnace gases directly inside the wall at the positions noted, drawn into a water-cooled collector, and thus immediately cooled. The amounts collected were too small for accurate analysis and it will be seen that the constituents determined do not total 100 per cent. The Fe_2O_3 content was, as with the other samples, greater than of the coal ash.

The second section of Table 3 presents the composition of samples of the ash and slags from this high-sulphur coal which was burned in the furnace from August 17 to 30, after the large masses of clinker, left from the previous run, had been removed from the walls. This coal ash contained 32.3 per cent flux as compared with 14.4 per cent for the low-sulphur coal; the principal difference was in the Fe_2O_3 content, which was more than three times greater. The softening temperature of the ash was lower by from 500 to 600 deg.

Fig. 13, at E and F, shows the walls at the close of the period of burning this coal; they now had only a thin coat of glassy slag except for the clinker left by the fuel bed. G and H, which are views of the bridge wall after the two runs, also show well the difference in character of the two slag coatings.

It was impossible to remove enough bricks to express quantitatively the erosion which had taken place. There was no uneven erosion or gouging out in the side walls. There were pockets eroded along the front wall above the tuyeres which it may be possible to distinguish in view E. The maximum depth of these was not greater than one inch.

The clinker and slag left along the fuel bed were of different character to that left from the low-sulphur coal. Whereas that from the low-sulphur coal consisted of a conglomerate mass of unfused material such as the white, flint-like material whose composition has been given above, held together by a fused glassy slag on the outside and running through it, this, from the high-sulphur coal, was more uniform in appearance. It was dark red in color, largely fused, and contained relatively small amounts of lighter unfused material. This slag adhered more strongly to the walls and, being thin, could not well be sampled for analysis.

Samples 77, 78, and 83, Table 3, were slags taken from the furnace gases when burning this coal. These show an increase in Fe_2O_3 content, but the percentage increase is not as great as in the samples from the low-sulphur coal.

Samples 32 and 74 were dusts taken from the soot chamber when burning the low- and high-sulphur coals, respectively. These were collected to serve as a check upon the sampling of the slags directly from the furnace gases as the material deposited in the soot chamber had been carried out of the furnace by the gases. Their compositions check fairly well with those of the samples taken from the gases, considering the fact that the latter are only approximate.

The increase in Fe_2O_3 contents of the various slag samples has been noted. The analyses of the samples taken from the ashpit, samples 41 and 73, show a decrease in iron content. This decrease is small because, as was pointed out above, the percentage of the total ash fired to the furnace which was carried up by the gases was small.

Samples 75 and 76 were of the outer and inner material taken from the boiler tubes. As had previously been observed in other installations, the alkali content of the material next to the cool surface of the tube was much greater than that of the outer material which remains in contact with the hot gases.

The ratio of the silica to the alumina content of each sample is given after its analysis. This ratio is almost the same for the ash and refuse samples as for the coal ashes, but is consistently lower for the slag samples except for sample 36.

In Fig. 13, E and F show that spalling had taken place on these walls which was not visible in the views with the heavy coating of slag. Inspection of the walls by tapping had shown the wall to be unsound. The washing by the fluid slag had merely rendered visible the spalling which had previously occurred. Pieces also probably fell away which had been formerly held by the slag coating.

Of the two types of slag action, that resulting from the high-sulphur coal was undoubtedly the more serious, and the life of the walls would have been shorter under these conditions.

There were probably several factors responsible for the erosion, the most obvious of which were the higher Fe_2O_3 content and lower softening temperature of the ash. These factors would render the erosion more serious if the furnace factors, temperature, and gas composition were the same. However, the maximum furnace-gas temperatures occurred and the average content of reducing gases was greater when burning the high-sulphur coal, which must have resulted from the higher volatile content of this coal and the lower excess of air.

The combustible content of the gases was highest at the lowest rating, particularly with the high-sulphur coal. The reason for this was the station practice of increasing the depth of the fuel bed at the lower ratings to decrease the excess air and thus raise the normally lower efficiencies at these ratings. So far as the reducing gases favor the formation of thinly fluid slags, this practice was conducive to slag erosion.

COMPARISON OF CONDITIONS IN UNDERFEED- AND CHAIN-GRATE-STOKER FURNACES

The high-sulphur coal used in this investigation was from the same field as that used in the investigation of conditions when burning Pittsburgh coal on chain grates. This afforded opportunity for comparison of service conditions and refractories service in these two types of furnace with the variable, type of coal, constant. A brief summary of the conditions follows, and those who

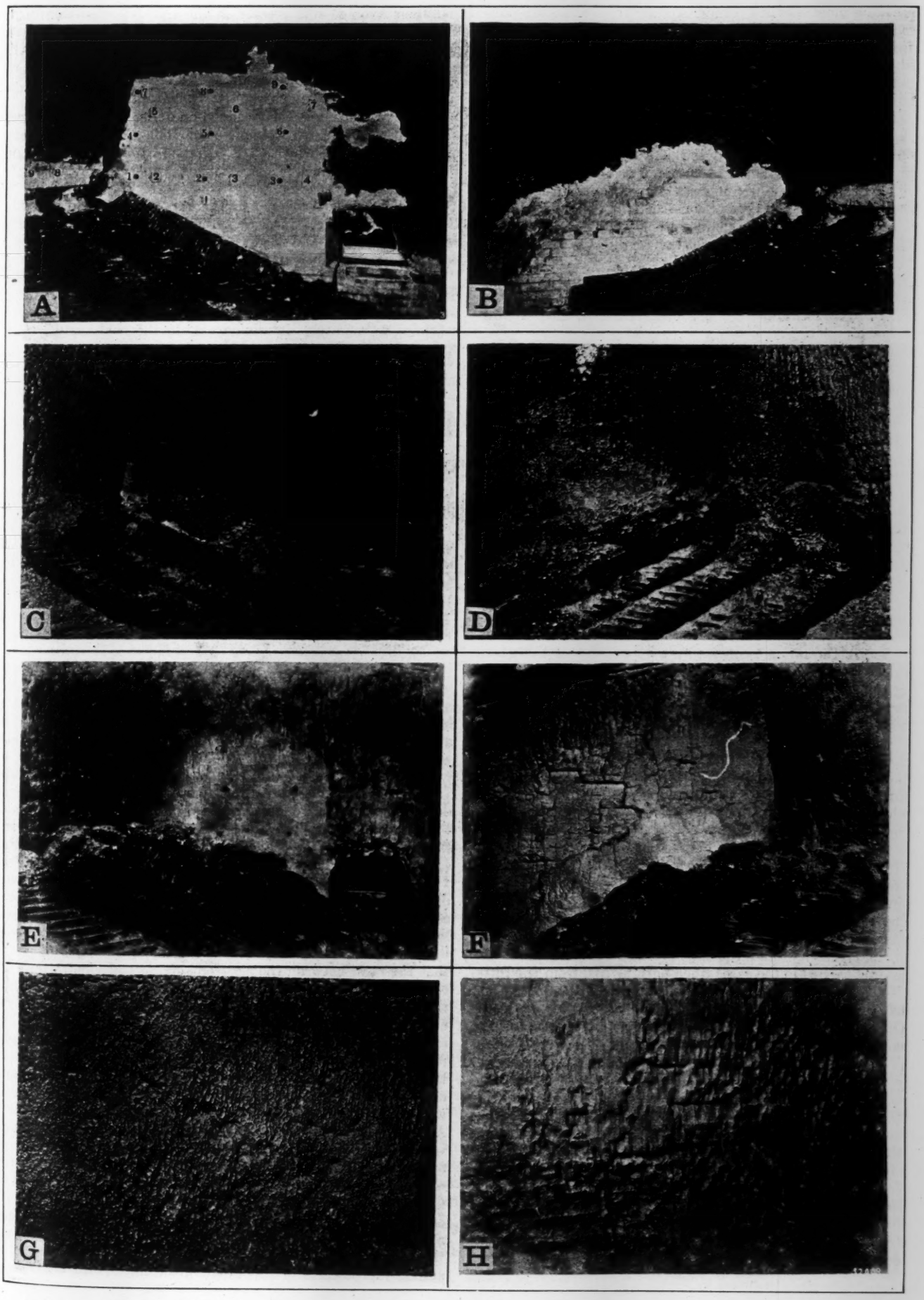

Fig. 13 Views of Underfeed-Stoker-Fired Furnace Burning Pittsburgh Coal

wish to make a more detailed comparison are referred to the published report of the earlier investigation.[4]

The furnace-gas temperatures in the chain-grate-stoker furnace averaged somewhat higher than in the underfeed-stoker furnace, although a few readings of relatively high temperature, 2750 deg., were taken in the latter furnace. The temperatures of the refractories in the side walls of the chain-grate-stoker furnace were not greatly higher than those in the underfeed-stoker furnace at similar boiler loads, but there was no part of the latter furnace which reached the high temperatures obtained in the arch of the former.

The differences in gas and refractories temperatures are obviously due to the difference in the type of construction of the furnaces, as the fuel bed and gases in the chain-grate-stoker furnace are confined under an arch where they cannot radiate directly to the boiler tubes.

The content of carbon monoxide and hydrogen in the furnace gases over the underfeed stoker reached higher values than over the chain-grate-stoker, and were also present over a greater area of the furnace.

The furnace-gas velocities were more uniform in the chain-grate- than in the underfeed-stoker furnace and the average velocity was greater, although the highest velocity measured in each was about the same.

The most striking difference between the service conditions in the two furnaces was the amount of material, ash and slag, carried in the gases. The amount in the two samples taken at the wall of the chain-grate-stoker furnace was more than 2 grams per 100 cu. ft., while in the underfeed-stoker furnace for the same coal it did not exceed 0.75 gram.

The primary cause of this difference was the difference between the thickness of the fuel beds; the fuel bed on the chain-grate stoker was 7 in. or less, and on the underfeed stoker, from 12 to 36 in. Uncaked coal dust, ash particles, and slag globules could be blown more easily from the thinner fuel bed.

The erosion of the side walls was not as great in the underfeed-stoker as in the chain-grate-stoker furnace, which is probably accounted for by the lower temperature and velocity of the gases, and the lesser amount of slag sprayed on the walls. The greater reducing content of the gases would tend to greater erosion of the underfeed-stoker-furnace walls, but this was apparently more than balanced by the other factors.

Examination of Refractories

Samples of new and slagged bricks and of slag from various parts of the furnace were collected for microscopic examination and other tests, which will be reported by the Columbus (Ohio) Branch of the Bureau of Standards.

Summary of Results

The results of the three objects of this investigation outlined in the introduction may be briefly summarized as follows:

1 The range of values of the refractories service conditions, namely, refractories temperatures, furnace-gas temperature, composition, and velocity, and the amount and composition of the solid material carried in the gases when burning coal from the Pittsburgh No. 8 bed on underfeed stokers, have been determined and recorded.

2 The temperature and reducing-gas content of the furnace gases were higher with the high-sulphur than with the low-sulphur coal. The sulphur content of the furnace gases was in approximately the same ratio as the sulphur content of the coals, and about one-half of the sulphur of the coal was in the gas at the points of sampling. The slag deposited on the walls by the low-sulphur coal was a heterogeneous, partly fused, thick coating which built up on the refractories; that deposited by the high-sulphur coal was mostly fused, more homogeneous, and thin, and eroded the refractories.

3 The furnace-gas temperatures were higher in the chain-grate-stoker furnace than in the underfeed-stoker furnace burning the same type of coal, while the content of reducing gases was greater over the underfeed stoker. The furnace-gas velocities were more uniform and their average was greater in the chain-grate-stoker furnace. The amount of slag carried in the furnace gases was considerably greater and refractories eroded at a more rapid rate in the chain-grate-stoker furnace.

[4] Refractories Service Conditions in Furnaces Burning Pittsburgh Coal on Chain Grates, by R. A. Sherman and W. E. Rice, MECHANICAL ENGINEERING, vol. 48, Nov., 1926, pp. 1115–1122.

Acknowledgments

This investigation is being carried on under the general direction of the Special Research Committee on Boiler-Furnace Refractories of the A.S.M.E. of which C. F. Hirshfeld is chairman, and under the direct supervision of P. Nicholls, supervising fuel engineer, Bureau of Mines.

The investigation covered in this report was made possible by the coöperation of A. Carnegie, superintendent of power, Pennsylvania-Ohio Power and Light Company, and the engineers and operators of the station.

The analyses of coal-ash and slag samples were made in the general analytical laboratory of the Bureau of Mines at Pittsburgh under the direction of W. A. Selvig, and the coal analyses and softening-temperature determinations in the coal-analysis laboratory under the direction of H. M. Cooper.

Discovery and Invention

DISCOVERY is essentially an increase in man's knowledge of nature and its complexities, and is therefore intangible. It may be a discovery of a new principle, a new element, a new and hitherto unknown quality or characteristic of a known substance, and so on, but the discovery, per se, has no regard to any particular practical application of the new knowledge. Invention, on the other hand, has its sphere in the practical application of knowledge, and the knowledge used may be new or may be as old as the hills. It may be and it is often the case, that invention involves other discoveries which may be complementary to the original discovery and form its completion, or may be entirely unrelated to it, and form the nucleus of a new branch of study. It is possibly this fact, that the difficulties encountered in developing an invention often lead to new discoveries, which makes it so difficult to separate discovery from invention. I think, however, that this distinction in general terms is sound, that discovery is mental while invention is material, and while it is true that in the large majority of cases an invention is in its origin a mental conception, it is a conception of something material and practical, while a discovery begins and ends in the realm of the mind.

When one seeks to study the history of some of the great inventions, one begins to realize how exceedingly complex they are, despite their outward appearance of simplicity. As an example take wireless telegraphy and telephony. No single person deserves the credit for its discovery and invention. Maxwell, Hertz, Lodge, Crookes, Branly, Marconi, Jackson, Fleming, De Forest, Fessenden and many others have contributed their share to its development, but the basis of wireless communication did not necessarily begin with Maxwell. What was it caused him to conceive the idea of the electromagnetic theory of light? Most probably he was trying to explain, like many others, the experimental fact that the ratio between the electromagnetic and electrostatic units was the velocity of light, and having conceived a possible explanation he proceeded to work it out and test it, and the electromagnetic theory was the result.

Hertz was the first to produce apparatus for transmitting and receiving wireless waves, and this apparatus was improved by Branly, Lodge, and many others, but for further progress finance was needed. The first steps to make a wireless telegraphic installation were taken in Italy by Marconi, and in Great Britain by the Admiralty experiments carried out by Admiral Sir Henry Jackson, who was then a captain. In this kind of competition money counts for much, and in the development of an invention having a commercial as well as a service aspect a commercial firm with good financial backing will always have a great advantage over a Government department with a strictly limited budget allowance for research. It says much, therefore, for the scientific direction of the Admiralty of that time that the Admiralty are today numbered among the pioneers of this great invention. (Prof. Sir James B. Henderson, D.Sc., in Presidential Address to Section G of the British Association, delivered at Leeds, September 1, 1927.)

Properties of Boiler Tubing at Elevated Temperatures Determined by Expansion Tests

By A. E. WHITE[1] and C. L. CLARK,[2] ANN ARBOR, MICH.

The object of this investigation was to determine safe working loads for low-carbon-steel seamless tubing at elevated temperatures.

Present-day boiler practice employs temperatures varying from 550 to 750 deg. fahr., and pressures of around 350 lb. per sq. in. There is an increasing tendency, however, to increase both temperature and pressure, but little is known of the properties of metals at elevated temperatures, particularly when temperatures are maintained for long periods of time.

The investigation recorded in this paper sets forth the preliminary findings on 0.13 carbon-steel tubing when loaded at temperatures of 900 1000, 1250, and 1500 deg. fahr.

PRESENT tendencies are daily calling for metal with high stability at elevated temperatures. Information in this field is most limited. The engineering profession has a vast amount of data with respect to the properties of metals at atmospheric temperatures, but little, if any, upon the properties of metals at elevated temperatures. Such work as has been done in the range of elevated temperatures has been in the nature of short-time tests. Even in this test field only a few of the possible metals and alloys have been studied.

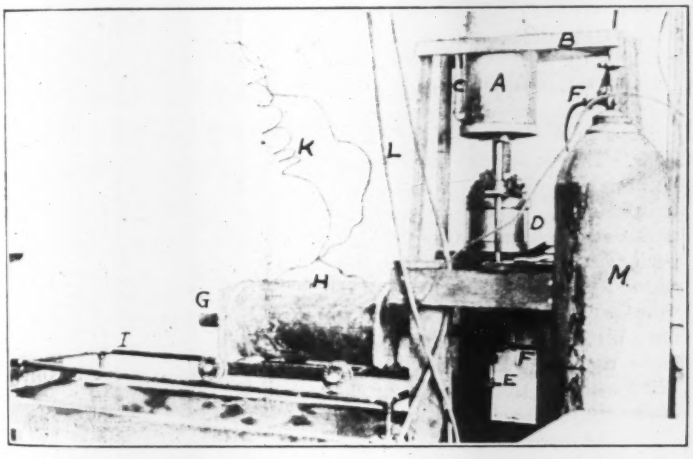

FIG. 1 GENERAL ARRANGEMENT OF EXPANSION-TEST APPARATUS

(A—Water tank; B—Water-tank support and guide; C—Water-tank gage; D—Pressure accumulator; B—Valve stem; F—Nitrogen-tank leads; G—End of test specimen; H—Electric furnace; I—Furnace tracks; K—Electric wires to furnace; L—Water-cooling jacket tubes; M—Nitrogen tank.)

Efforts have been made to develop short-time tests which would give an indication of the stability of metal under prolonged heating. A number of investigators have arrived at the conclusion that metal is stable at all loads which are under the proportional limit for the temperature used, irrespective of the length of time at which the metal is held at the given temperature under the given load. The findings of the authors do not agree with this observation; at least in so far as temperatures of 1250 and 1500 deg. fahr. are concerned. They are inclined to believe that the observation is not correct for lower temperatures, although they have not sufficient data at this moment to support their contention. They are working on this phase of the problem, however, and hope to have further data within a year.

The paper is given with due appreciation of the fact that the data are incomplete, but because of the importance of the subject the authors feel warranted in presenting it at this time. Future studies contemplate analyzing the problem more fully, covering further study of plain carbon and alloy steels, as well as other alloys at various high temperatures. Attention is specifically called to the fact that, in the opinion of the authors, no design involving the use of materials at elevated temperatures should be based on short-time proportional-limit values.

The data in this paper have been confined to 0.13 per cent carbon steel. The determinations were made on tubing. The results show that at 1500 deg. fahr. a load of 595 lb. per sq. in. would ultimately result in failure, although the short-time test showed the metal to have a proportional limit of 1880 lb. per sq. in. Failure would be expected at a load under 595 lb. per sq. in., although no data are available on this point, except that a tube with a load of 106 lb. per sq. in. did not expand after 540 hours at heat, although it was so badly oxidized that with continued heating it would ultimately have failed from this cause.

The short-time, high-temperature tests at 1250 deg. fahr. gave for the 0.13 carbon steel a proportional limit of 3050 lb. per sq. in. The long-time tests indicated that loads under 213 lb. per sq. in. could not successfully be applied over any long period of time, in view of the fact that a tube subjected to 213 lb. per sq. in. manifested marked expansion at the end of 482¾ hours.

The data for 1000 and 900 deg. fahr. are not complete, and no conclusions can be drawn. The information is presented because it may be of some service at this time to designing engineers.

Apparatus Used

The apparatus used in this work consisted of a pressure accumulator, a valve arrangement, a test specimen in the shape of a seamless steel tube 30 in. long, and a movable furnace mounted on a track. See Fig. 1.

A sketch of the pressure accumulators used is given in Fig. 2. The small pistons exposed to the oil and to the nitrogen had a diameter of 1 in. in each case while the size of the large pistons working against the oil varied in the different accumulators used, one being 6 in., one 4 in., and one 2.5 in. in diameter. Therefore, any load applied to these accumulators was multiplied 36, 16, and 6.25 times, respectively.

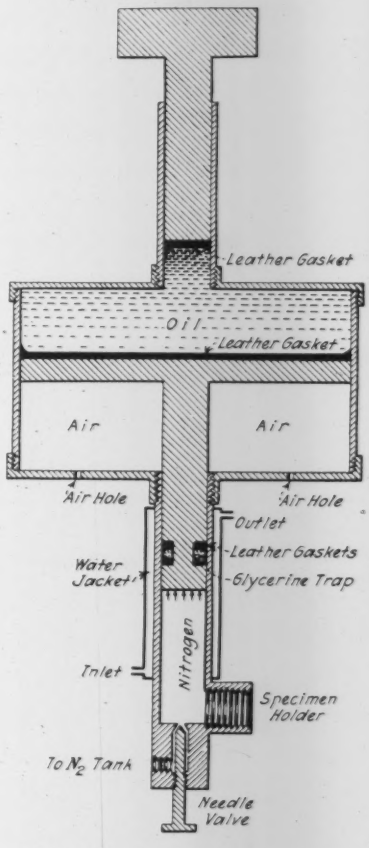

FIG. 2 PRESSURE ACCUMULATOR

Leather gaskets were used on the surfaces of the pistons exposed to the oil and worked very well. Much trouble was experienced in making the pistons working against nitrogen leakproof. This was finally overcome by the use of a glycerine trap. A water jacket was added so as to reduce thermal expansion to a minimum, as well as to prevent the glycerine from vaporizing.

A needle valve was found to give the most satisfactory results.

Fig. 3 shows the specimens used in both the tensile and pressure tests. The only trouble found in the use of this type of pressure specimen was in making the cap leakproof. The difficulty was finally solved by brazing on steel caps.

[1] Professor of Metallurgical Engineering and Director of Department of Engineering Research at the University of Michigan. Mem. A.S.M.E.

[2] Holder of The Detroit Edison Fellowship in Metallurgy at the University of Michigan.

Contributed by the Power Division and presented at the Annual Meeting, New York, December 6 to 9, 1926, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Abridged.

In using the tensile-test specimen, steel plugs were inserted in those parts of the specimen held by the jaws, so as to prevent crushing. A Riehlé tensile machine of 50,000 lb. capacity was used in all the tensile tests.

The type of furnace used in both the tensile and rupture tests is shown in Fig. 4. The furnaces differed in size only.

For low-pressure rupture tests, the specimen was first brought to the required temperature and nitrogen introduced until the desired pressure was obtained. The pressure was measured by means of a graduated tank placed on the upper piston of the accumulator. Water was used for balancing the pressure, as this allowed more accurate balancing than could be obtained with solid weights. For the higher pressures, lead weights also were added, but the final adjustment of load was obtained with water. By keeping

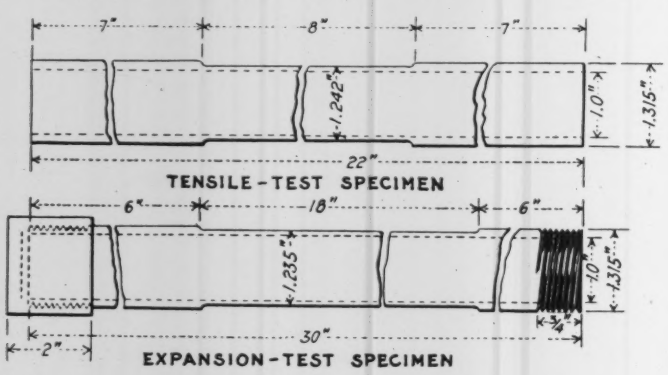

FIG. 3 TYPES OF SPECIMENS USED

the piston balanced, the pressure was accurately measured at all times.

In order to convert the load from lb. per sq. in. of interior surface to tensile stress in the tube walls, the following relations were used:

$$\text{Tension force in tube} = \frac{(\text{lb. per sq. in. of interior surface}) \times (\text{diam. in in.})}{2}$$

$$\text{Tension force in lb. per sq. in.} = \frac{\text{tension force in tube}}{(\text{thickness of tube in in.}) \times (\text{unit length in in.})}$$

After the specimen had attained the right temperature and pressure, the temperature was held constant and the diameter of the tube measured at regular intervals. This was accomplished by running the furnace away from the heating position and using calipers on the tube. In case the diameter was enlarged, the run was considered complete. Otherwise, the run was continued until enlargement or actual rupture occurred, or, for various reasons, the test was discontinued.

RESULTS OF TESTS

Chemical Analyses. Upon chemical analysis, the steel tubing was found to have the following percentage composition: C, 0.13; Mn, 0.29; S, 0.044; P, 0.010.

The microstructure of the tubing in the condition in which it was received was that of a typical low-carbon pearlitic steel. The crystals were fairly uniform in size and shape and equi-axed, indicating the metal to be in a fully annealed condition.

Short-Time Tensile Tests. The tubing was subjected to tensile tests at temperatures of 70, 500, 750, 1000, 1250, and 1500 deg. fahr. The results obtained are given in Table 1 and Fig. 5.

From the curves, it can be seen that the tensile strength increases up to 500 deg. fahr. and then decreases rapidly with further increases of temperature. The proportional limit decreases continuously as the temperature is raised. The elongation decreases to 500 deg. fahr. and then increases rapidly. The reduction of area could not be determined because of the shape of the specimen used.

These tests are in close agreement with the work of other investigators when determining the properties of low-carbon steel

TABLE 1 SHORT-TIME TENSILE TESTS AT ELEVATED TEMPERATURES

Temp., deg. fahr.	Proportional limit, lb. per sq. in.	Tensile strength, lb. per sq. in.	Elongation, per cent in 2 in.
70	30,500	53,520	43.75
500	13,612	62,215	33.50
750	10,800	34,030	54.00
1000	3,750	17,370	62.50
1250	3,050	8,860	92.00
1500	1,880	7,000	*

NOTE. Test specimens used as shown in Fig. 3.
* Elongation not determined, as all gage marks were destroyed at this temperature.

by short-time tests at elevated temperatures. The metallographical structures for some of the samples after test are given in Figs. 6 to 9, inclusive. Although pains were taken to examine the specimens at the point of rupture, yet the sections from the specimens broken at elevated temperatures are little, if any, different from the sections obtained from the sample tested at atmospheric temperature.

Expansion Tests at 1500 Deg. Fahr. Data of six tests at 1500 deg. fahr. are submitted. The data are given in Table 2 and Fig. 10. Two of the tests were run at loads below the proportional limit determined in the short-time tests. Both of these show decided expansion at loads under the proportional limit. The test employing a tensile load of 106 lb. per sq. in. showed no expansion after 540 hours of heating, but in time the tube would have failed from oxidation.

Expansion Tests at 1250 Deg. Fahr. Eleven tests in all were run. Although in the short-time high-temperature test the proportional limit was determined as 3050 lb. per sq. in., yet the expansion tests showed decided enlargement of the tubes with loads as low as 213 lb. per sq. in. Seven of the tests, with loads ranging from 2834 down to 213 lb. per sq. in., were under that of the short-time proportional-limit value for 1250 deg. fahr., yet all showed expansion and all of the tubes would undoubtedly have failed had the test been of longer duration.

The data are given in Table 3 and in Fig. 11. Attempts were made to convert these data into a mathematical expression. One expression, derived directly from the data, is as follows:

$$S = 200 + 2800e^{-0.75t}$$

In which S = stress in lb. per sq. in., e = Napierian base, and t = time in 100 hr. Another was worked out on the basis of the data in accordance with a mathematical interpretation of a supposed molecular transformation going on in the material under the influence of high temperature, namely,

$$S = 30{,}000e^{-1.5t} + 200(1 - e^{-1.5t})$$

The curve derived from a plotting of the data checks closely

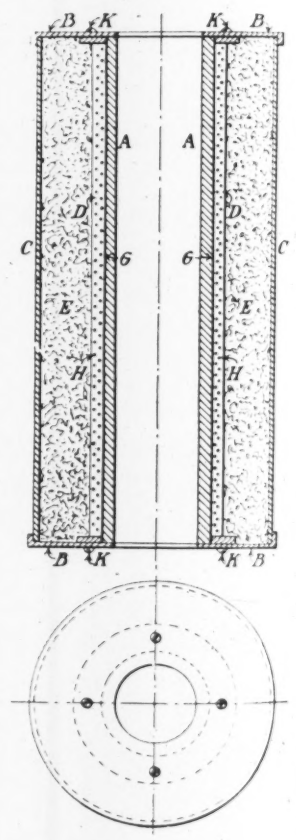

FIG. 4 TYPE OF FURNACE USED
(A—Inner iron tube; B—Sheet-steel end plates, 3/16 in.; C—Sheet-steel outer tube, 3/16 in.; D—Alundum cement; E—Sil-o-Cel insulation; G—Asbestos covering; H—Two coils of chromel A-14-gage wire connected in parallel, resistance, 0.1625 ohm per ft.; K—End-plate screws.)

TABLE 2 RESULTS OF EXPANSION TESTS AT 1500 DEG. FAHR. (815 DEG. CENT.)

Specimen, No.	Lb. per sq. in. interior surface	Tensile stress, lb. per sq. in.	Diam. of tube, in.		Time for expansion, hr.
			Initial	Final	
9	665	2834	1.235	1.400	0.75
7	634	2696	1.235	1.314	1.50
17	466	1982	1.235	1.295	2.00
13	300	1276	1.235	1.261	3.00
14	140	595	1.235	1.268	10.00
26	25	106	1.235	.....	*

* Not expanded after 540 hr., very badly oxidized.

TABLE 3 RESULTS OF EXPANSION TESTS AT 1250 DEG. FAHR. (677 DEG. CENT.)

Specimen No.	Lb. per sq. in., interior surface	Tensile stress, lb. per sq. in.	Diam. of tube, in.		Time for expansion, hr.
			Initial	Final	
16	1030	4383	1.235	1.250	2.50
15	750	3192	1.235	1.250	4.00
10	665	2834	1.235	1.300	5.00
12	614	2611	1.235	1.368	18.00
19	600	2582	1.235	1.287	19.25
11	550	2350	1.235	.....	*35.00
20	477	2024	1.235	1.255	61.25
21	355	1510	1.235	1.261	139.00
22	250	1064	1.235	1.264	208.50
23	130	553	1.235	1.266	285.50
24	50	213	1.235	1.262	482.75

*Tube removed at end of 35 hr. unexpanded.

with the curve derived from the use of the first formula. The curve drawn from the equation setting forth the supposed molecular transformation checks with the curve drawn from the data with heating exposures of 200 hours or greater.

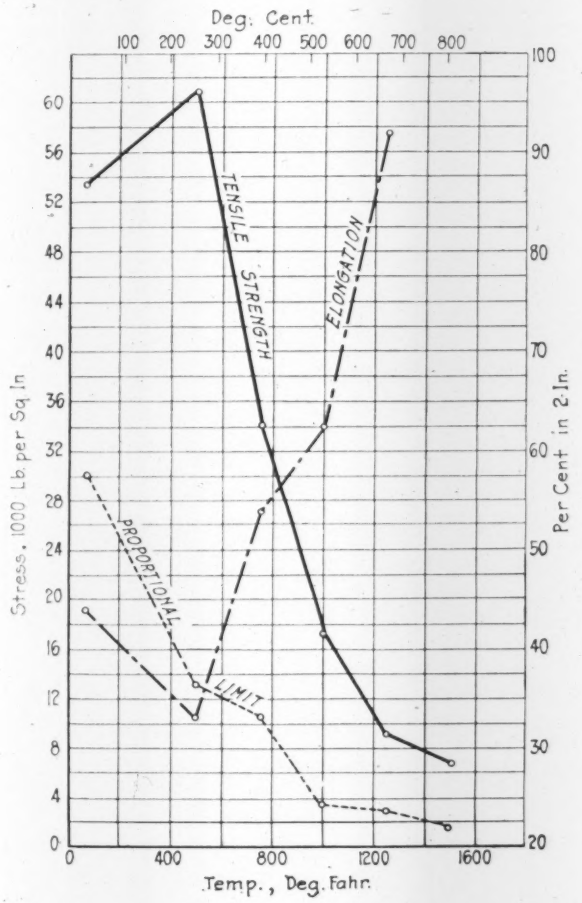

FIG. 5 PROPERTIES AT ELEVATED TEMPERATURES OF 0.13 CARBON STEEL. SHORT-TIME TENSILE TESTS

Expansion Tests at 1000 Deg. Fahr. and 900 Deg. Fahr. Incomplete data of some preliminary tests run at these temperatures appear to indicate that between 1000 deg. fahr. and 1250 deg. fahr. there is a sharp decrease in strength. The data are given in Table 4 and in Figs. 12 and 13.

CONCLUSIONS

Possibly one of the most significant features of the test is the

TABLE 4 RESULTS OF EXPANSION TESTS AT 1000 DEG. FAHR. (538 DEG. CENT.)

Specimen No.	Lb. per sq. in., interior surface	Tensile stress, lb. per sq. in.	Diam. of tube, in.		Time for expansion, hr.
			Initial	Final	
Results of expansion tests at 1000 deg. fahr. (538 deg. cent.)					
18	1150	4893	1.235	1.260	43.25
27	450	1914	1.235	.....	*
28	1000	4250	1.235	1.260	100.00
Results of expansion tests at 900 deg. fahr. (482 deg. cent.)					
29	800	3404	1.235	.....	*

* Not expanded after 1080 hours.

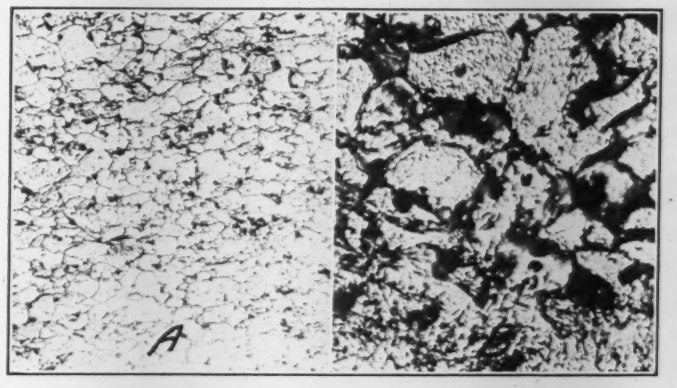

FIG. 6 SHORT-TIME TENSILE TEST, 70 DEG. FAHR. (21 DEG. CENT.). ETCHED WITH 4 PER CENT HNO_3 IN ALCOHOL (A—Magnified 100 times; B—Magnified 500 times.)

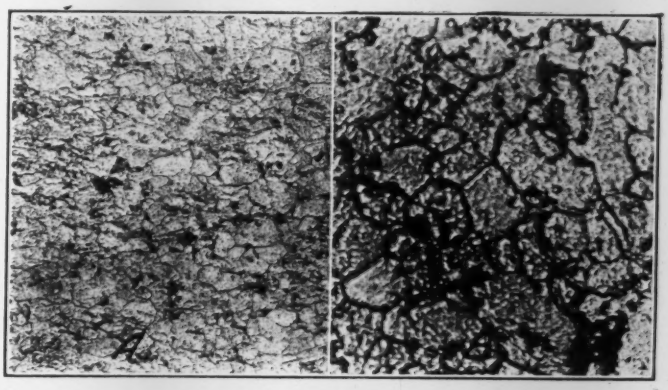

FIG. 7 SHORT-TIME TENSILE TEST, 500 DEG. FAHR. (260 DEG. CENT.). ETCHED WITH 4 PER CENT HNO_3 IN ALCOHOL (A—Magnified 100 times; B—Magnified 500 times.)

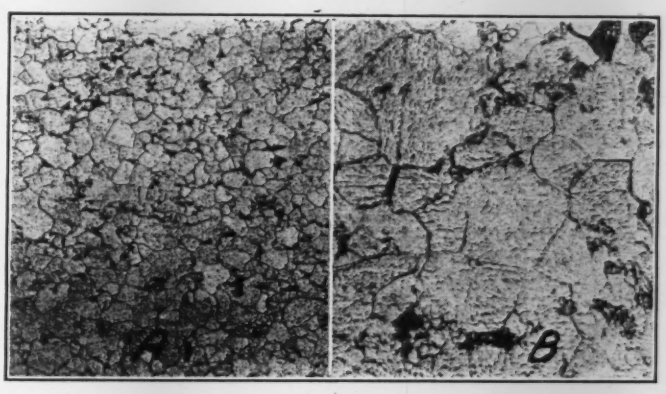

FIG. 8 SHORT-TIME TENSILE TEST, 1000 DEG. FAHR. (538 DEG. CENT.). ETCHED WITH 4 PER CENT HNO_3 IN ALCOHOL (A—Magnified 100 times; B—Magnified 500 times.)

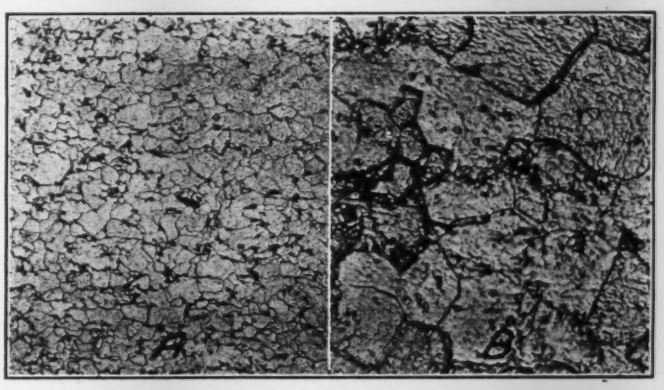

FIG. 9 SHORT-TIME TENSILE TEST, 1500 DEG. FAHR. (815 DEG. CENT.). ETCHED WITH 4 PER CENT HNO_3 IN ALCOHOL (A—Magnified 100 times; B—Magnified 500 times.)

fact that for temperatures of 1500 and 1250 deg. fahr., at least, *the proportional limit, as ordinarily determined, was found not to be the criterion of stability*. The authors are under the impression that it will be the criterion for stability, at other temperatures. These statements are made with due caution, appreciating the fact

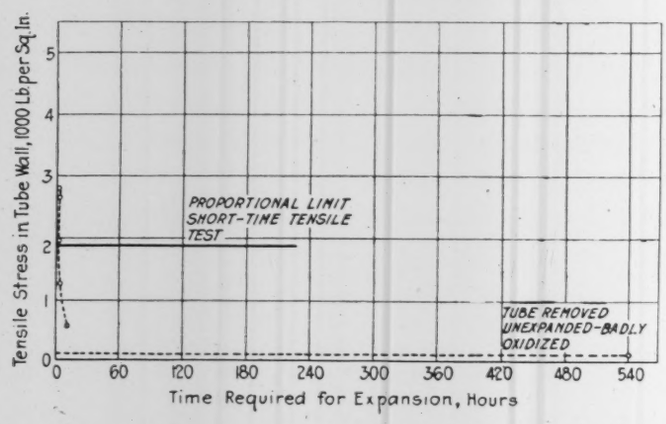
Tensile Stress in Tube Wall, 1000 Lb per Sq In.
PROPORTIONAL LIMIT SHORT-TIME TENSILE TEST
TUBE REMOVED UNEXPANDED-BADLY OXIDIZED
Time Required for Expansion, Hours

FIG. 10 EXPANSION TESTS ON 0.13 CARBON STEEL AT 1500 DEG. FAHR. (815 DEG. CENT.)

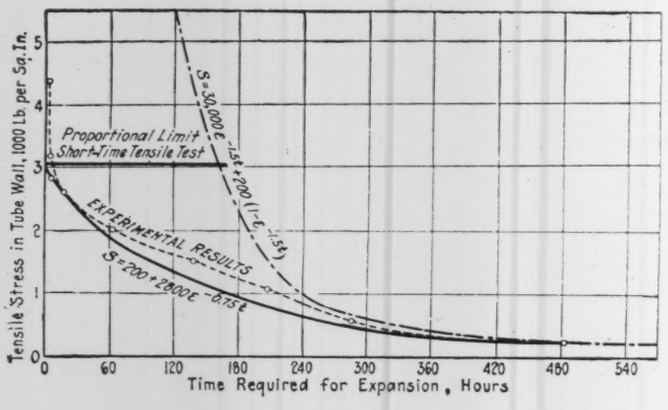
Tensile Stress in Tube Wall, 1000 Lb. per Sq. In.
Proportional Limit Short-Time Tensile Test
EXPERIMENTAL RESULTS
Time Required for Expansion, Hours

FIG. 11 EXPANSION TESTS ON 0.13 CARBON STEEL AT 1250 DEG. FAHR. (675 DEG. CENT.)

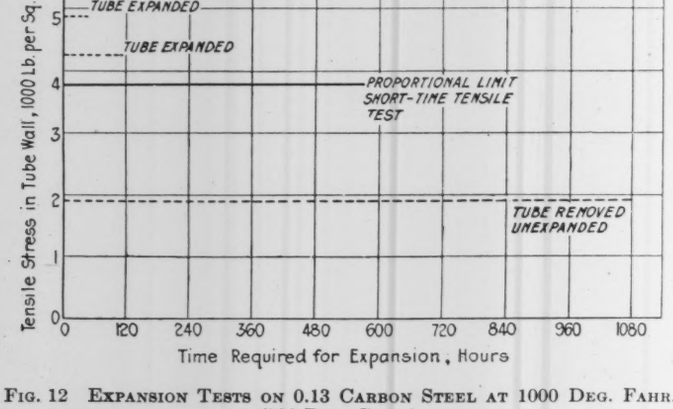
TUBE EXPANDED
TUBE EXPANDED
PROPORTIONAL LIMIT SHORT-TIME TENSILE TEST
TUBE REMOVED UNEXPANDED
Tensile Stress in Tube Wall, 1000 Lb. per Sq. In.
Time Required for Expansion, Hours

FIG. 12 EXPANSION TESTS ON 0.13 CARBON STEEL AT 1000 DEG. FAHR. (538 DEG. CENT.)

that more careful methods of obtaining proportional limits may make more justifiable the claims of those who hold that loads under the proportional limit for any given temperature may safely be used. Yet, the authors would point out that their proportional-limit findings check quite closely those of other investigators whose works are recognized as of a high degree of accuracy. Therefore, it is suggested for engineering design that, until more data are available, no regard be given to the present-day proportional-limit values for elevated temperatures, or if used, then only with an adequate factor of safety.

Discussion

H. J. FRENCH[3] wrote that data given in Table 1 showed that in the range of 1000 to 1250 deg. fahr., where the tensile strength of the 0.13 per cent carbon steel dropped about 50 per cent, the drop in proportional limit as determined by the authors was only from 3750 to 3050 lb. per sq. in. This lack of appreciable change in numerical values of the proportional limit, as the temperature was raised from 1000 to 1250 deg. fahr., was so at variance with what could justly be expected from a large mass of available data on low-carbon steels, that the reaction on reading the paper was that the authors' determinations of the proportional limits at temperatures of 1250 deg. fahr. and above must be highly inaccurate.

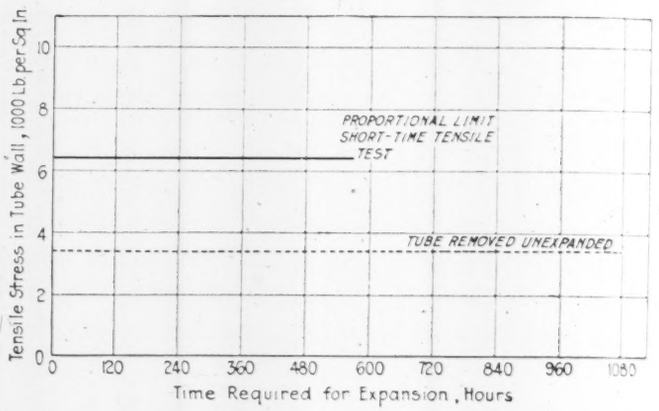
Tensile Stress in Tube Wall, 1000 Lb per Sq In.
PROPORTIONAL LIMIT SHORT-TIME TENSILE TEST
TUBE REMOVED UNEXPANDED
Time Required for Expansion, Hours

FIG. 13 EXPANSION TESTS ON 0.13 CARBON STEEL AT 900 DEG. FAHR. (482 DEG. CENT.)

It was fairly well recognized that roughly determined proportional limits would differ more widely from values of load-carrying ability, as the temperature at which the tests were carried out was increased. Even the authors' proportional limit determinations at 1000 and 900 deg. fahr. and the incomplete pressure tests of the tubes recorded in Figs. 12 and 13 fell in line with the view which had been expressed by Lynch, McVetty and Mochel, Malcolm, the writer, and others, to the effect that "creep" occurred at stresses above the proportional limit, and did not occur at stresses well below, provided always that the proportional limit was determined with suitably sensitive equipment.

Being unable to accept all of the proportional-limit values given by the authors, the writer also was unable to accept the implied conclusions to the effect that the authors were under the impression that the proportional limit was not a criterion of stability at any temperature between that of the room and 1500 deg. fahr.

E. C. Wright[4] wrote that the type of test outlined by the authors appeared to be particularly valuable because it approximated service conditions and it was hoped that the further tests would give more complete data.

The main deduction which the authors made was that the proportional limit was not a safe maximum stress at which metal could be used at elevated temperatures, and while the writer did not feel that this proposition was sufficiently established, it was not apparent that the authors' data refuted this idea. Proportional-limit determinations required the most careful experimental procedure, and the gaging of the test piece cross-section to enable unit-stress calculations must be very precise. While the authors did not specify whether the tubes used were of the welded or seamless (weldless) variety, it was assumed that the latter was the more probable. As the proportional-limit determinations were made on full sections it was certain that no accurate unit-stress calculations could be made on such test sections on account of the eccentricity of the metal wall in such products. The original tubing used in these tests had the dimensions 1.315 in. O.D. by 0.179 in. wall thickness. In this size, the seamless tubes were made cold drawn and then given a 700 deg. cent. anneal. The commercial tolerance on this wall thickness, however, was plus or minus 10

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[4] Metallurgical Engineer, National Tube Co., Ellwood City, Pa.

per cent, and tubes made to this average size by the weldless mill would thus vary from 0.161 to 0.197 in. in wall thickness. Turning these tubes down to an outside diameter of 1.242 in. for the gage length of the test specimen would merely accentuate the variation in eccentricity. Certainly no accurate proportional-limit determinations could be made on sections which were not exactly concentric.

If the tubes were exactly concentric, at a pressure of 100 lb. per sq. in. the fiber stress as calculated by the formula used by the authors would be 425 lb. per sq. in. If the original tube had the maximum allowable eccentricity of 10 per cent the wall thickness would vary between 0.1395 in. and 0.1705 in. Turning the tube outside diameter to 1.235 in. merely took 0.04 in. off of the wall thickness and left the minimum wall at 0.0995 in. and the maximum at 0.1305 in. Thus, at the pressure of 100 lb. per sq. in. the fiber stress at the light portion of the wall would be 502 lb. per sq. in., a variation of 17.6 per cent between the maximum and average fiber stress.

Moreover, the formula used for transposing the static pressures into fiber stresses was known to be inaccurate in tubing of a high ratio of wall thickness to outside diameter. In short tube lengths such as were used, there was also a longitudinal tension in the tube due to the end pressures. Two other formulas which are used commonly for heavy-wall tubing were those of Barlow and Clavarino. Barlow's formula usually gave fiber stresses which were slightly high, while Clavarino's formula gave results which were more nearly theoretically correct.

Referring to Table 3, at a pressure of 1030 lb. the stress calculated was 4383 lb. per sq. in., while at this pressure Barlow's formula yielded 5420 lb. per sq. in., and Clavarino's formula 4675 lb. per sq. in. Here was a variation of 23.6 per cent using Barlow's formula, and 6.65 per cent, using Clavarino's formula. As the latter formula included consideration of the elasticity of the material and the effect of end pressures, it was probably more nearly correct than the other two formulas, but actual bursting tests indicated that the calculated stresses were slightly low. Apparently the authors' stress calculations were about 8 to 10 per cent too low.

Referring again to Table 3, it would be noted that tubes were considered as having expanded due to the stress when the outside diameter at 677 deg. cent. was 1.250, 1.255, 1.261, 1.262, etc. At this temperature the room-temperature outside diameter of 1.235 would expand to 1.247, and the method described for gaging would hardly detect variations of 0.003 to 0.008 in. Furthermore, the scaled surface of these tubes, especially in the long-extended tests, would render the detection of such slight gage variations highly questionable.

This type of testing was similar to the work which Dickenson[5] had carried out in England, although his test stresses were over the proportional limit at the temperature of the test. On the other hand, there were several boilers operating at 300 and 400 lb. pressure with tube sizes of 4 in. O.D. and 0.185 in. wall in which the fiber stresses varied between 3000 and 4300 lb. per sq. in. in the tubes, and reached 3700 to 4000 lb. per sq. in. in the 2-in. O.D. by 11-gage superheater tubes. Although the operating temperatures were below those of the authors' tests, the temperature of these tubes might exceed 400 deg. cent. when somewhat scaled on the inside, and these tubes were quite generally giving satisfactory service at much longer periods than those indicated in the paper. In this respect these experimental data were actually contradictory to established engineering facts.

Tests and Theory of Curved Beams

By A. M. WINSLOW[1] and R. H. G. EDMONDS,[2] SEATTLE, WASH.

Despite the fact that curved beams comprise such important machine elements as crane hooks and punch frames, previous laboratory tests have been, in general, of meager scope and uncertain interpretation. The laws of stress distribution, therefore, are subject to diverse opinions among prominent engineers. The present tests consist of strain-gage observations at several points throughout the cross-sections of large steel specimens, determining complete strain curves. Radial strains, apparently not previously investigated, are definitely measured and a simple working theory of radial stress is developed. Stress in a radial direction is shown to be a vital factor in the design of curved beams of certain proportions. Finally, different theories of circumferential stress are investigated, both by comparison with tests and by analysis; prominent fallacies are pointed out and a more logical fundamental hypothesis advanced in support of the theory adopted.

TESTS of curved beams hitherto published have consisted mainly of attempts to determine maximum stress by observing the apparent proportional elastic limit of curved members in bending and comparing this result with the elastic limit of straight-bar tension specimens of the same material.[3] This method is indirect, the theoretical validity of the comparison has been questioned, and the observed proportional limit has been in many cases poorly defined. Furthermore, comparison of test results with theory has been hampered in some cases by the necessity of graphical calculation in the numerical application of theory. The graphical solution happens to involve terms so related that any lack of precision in graphics produces a greatly magnified error in the final result.[4] The purpose of the present tests was to investigate more definitely and completely the stresses in curved beams of assumedly isotropic material. Specimens were made simple in shape to permit precise numerical computations without graphics, and also sufficiently large for strain-gage observations at several points in the cross-section. One valuable result of this latter condition was the immediate check on the instrument work; with observations sufficient in number to determine a strain curve, a departure from the average curve was at once discovered and the point reëxamined.

Description of Specimens and Testing Apparatus

The curved specimens were mild-steel plates, of rectangular cross-section, machined all over to finished dimensions noted in Fig. 1, *A* and *B*. Lack of a horizontal testing machine, together with the desirability of using the strain gage on a horizontal surface, led to the construction of the loading frame shown in Fig. 2. This frame consisted of a pair of steel-channel levers at the outer end of which force was applied by a turnbuckle through a calibrated tension dynamometer. The levers were supported near the fulcrum points. The curved beam was supported on rollers. At times of applying load the levers were repeatedly raised slightly above their supports in order to eliminate the effects of friction as far as possible.

The strain-gage readings were taken on 1-in. spans at the stations indicated in Fig. 1, *A* and *B*. The strain observations were made both circumferentially and radially, the latter readings in specimen *A* being made along lines *ef* and *gh*. In specimen *B*, after the circumferential readings were completed, additional station points were made by adding center-punched holes along the radial line *OO'*. The Olsen strain-gage extensometer, shown in Fig. 3, has contact points adjustable for either a 1-in. or a 2-in. span. The gage is intended to be used either in center-punched holes or in holes drilled $1/16$ in. in diameter; the latter were used in all places except along the radial lines of specimen *B* already noted. Fig. 3 also shows a lateral arm $1/4$ in. square by 6 in. long which

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[2] Assistant Professor of Mechanical Engineering, University of Washington. Assoc-Mem. A.S.M.E.

[3] Walter Rautenstrauch, Trans. A.S.M.E., vol. 31 (1909), p. 559.

[4] Arthur Morley, *Engineering*, vol. 98, p. 321.

Presented at the Annual Meeting, New York, December 6 to 9, 1926, of The American Society of Mechanical Engineers. Abridged.

[5] Dickenson, J. H. S., Jour. Iron & Steel Inst., vol. 106, p. 103.

was added in order to support the instrument normal to the surface. In taking observations the instrument points were pressed downward on the specimen and at the same time a slight lateral vibration was applied at the outer end of the arm in order to permit the instrument points to seat in complete contact. A single schedule of observations, for example with specimen *B*, consisted of sets of strain readings at four successive loads, of 100 lb. and 1200 lb. alternately, followed by comparisons of each two sets of readings at equal loads. In observations the position of the pointer on the dial was estimated to the nearest one-fourth

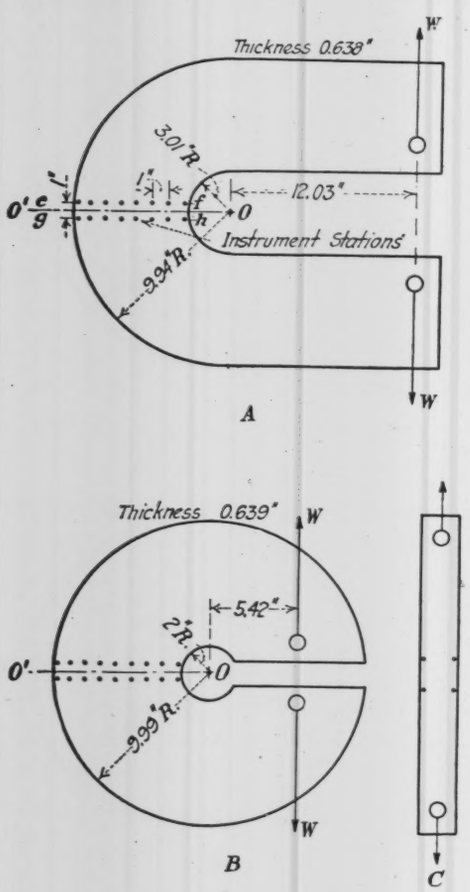

FIG. 1 DETAILS OF SPECIMENS

of the smallest graduated interval, the one-fourth interval corresponding to a strain difference of 0.000015 in. per in.

STRAIN-GAGE RESULTS

The strain-gage readings are shown in Tables 1 to 4, inclusive, of the complete paper, and the average values are plotted in Figs. 5 and 7, with a smooth average curve drawn for each set of plotted points.

The mathematical analysis of radial stresses developed later in this paper involves the necessity of determining Poisson's ratio of lateral strain. This value, together with the modulus of elasticity, was obtained by testing straight-bar tension specimens cut from the original plates *A* and *B*. These tension bars, $2^1/_2$ in. wide and approximately 21 in. long, had gage-setting holes on 2-in. spans arranged as shown in Fig. 1*C*, permitting strain observations both longitudinally and transversely on both sides of the specimen. The average results of the twelve sets of observations for each tension bar were as follows:

	A	*B*
Load, lb. per sq. in.	6,420	11,310
Longitudinal strain, in. per in.	0.0002208	0.000390
Transverse strain, in. per in.	0.0000546	0.000102
Modulus of elasticity	29,100,000	29,000,000
Poisson's ratio	0.247	0.262

For the two specimens the average value of Poisson's ratio is 0.255. For convenience the value 0.25 was used in all numerical computations; this is the theoretical value for isotropic materials, and furthermore a small change in the value of Poisson's ratio produces only a very slight change in the final numerical results for curved beams.

Before interpreting further the results of these tests, it is necessary to consider certain theoretical relations. Up to the present time, three leading theories have been advanced to express the distribution of stresses in curved beams subjected to bending. The three mathematical formulas, already fully stated in several previous publications, need not be repeated in detail.[5] It is essential here simply to note the general principles and hypotheses underlying each theory, as follows:

1 The ordinary beam theory assumes that in the cross-section of a curved beam the stresses due to bending are distributed according to the same law as in the case of a straight beam

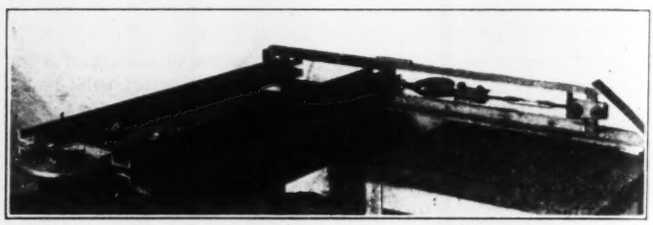

FIG. 2 LOADING FRAME

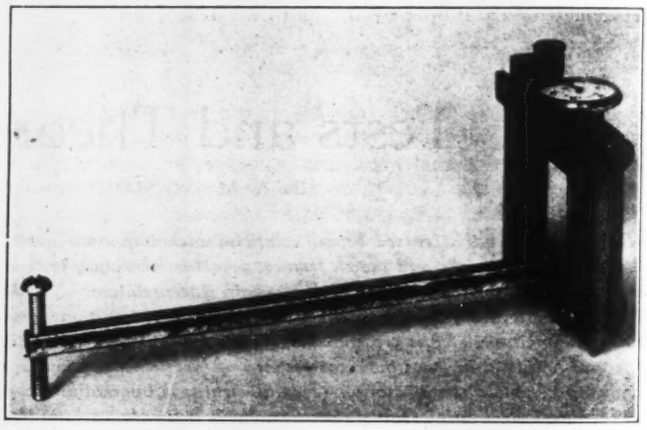

FIG. 3 STRAIN GAGE

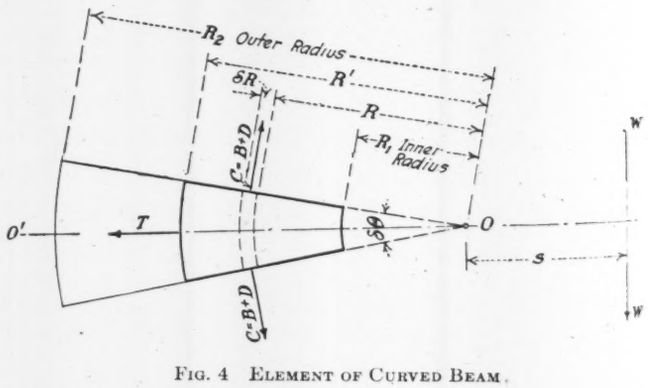

FIG. 4 ELEMENT OF CURVED BEAM

2 Winkler's theory takes account of curvature and is based on the hypothesis that plane transverse sections remain plane after loading

3 The Andrews-Pearson theory, proposed as a refinement of the Winkler theory, takes account of the additional consideration that the radial dimensions of the cross-section after loading are changed by the Poisson ratio effect of transverse strains resulting from normal stresses.

[5] Arthur Morley, *Engineering*, vol. 98, p. 321.

It should also be noted that both the Winkler and the Andrews-Pearson theory, to reduce complexity, confine consideration to the plane of maximum moment OO', Fig. 1, normal to direction of loading. On this plane the resultant external shear is zero, and it is assumed that internal shearing stresses on this plane may be neglected without appreciable error.

RADIAL STRESSES

The first investigations by the authors were with specimen B, on which strains were observed in a circumferential direction only. These results, compared directly with the Winkler and Andrews-Pearson theories, continued to show pronounced unbalanced discrepancies, despite much experimental revision of testing procedure. Consideration finally indicated the possibility that the circumferential strains were modified by the effect of tensile or compressive stresses in a transverse radial direction. With normal unit stresses, C circumferentially and T radially, the resulting unit strains, denoted by small letters c and t, produced by Poisson's ratio m are as follows, E denoting modulus of elasticity:

$$c = \frac{1}{E}(C - mT); \quad t = \frac{1}{E}(T - mC)$$

from which

$$\left.\begin{aligned} C &= \frac{E}{1 - m^2}(c + mt) \\ T &= \frac{E}{1 - m^2}(t + mc) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots [1]$$

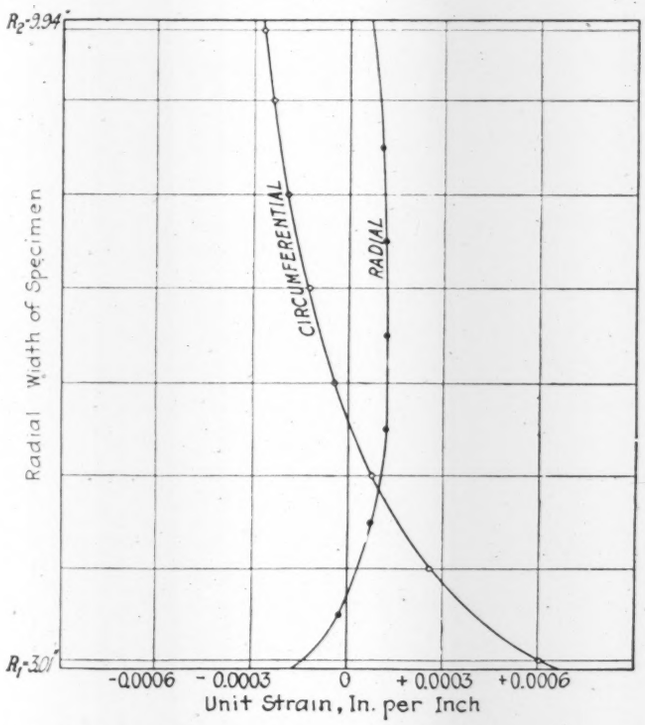

FIG. 5 CIRCUMFERENTIAL AND RADIAL STRAINS; SPECIMEN *A*. TEST VALUES WITH AVERAGE CURVES

To investigate the above relations more readily, specimen A was made with instrument-station holes arranged for observation of strains both radially and circumferentially; specimen B was later arranged for testing radial strains.

The numerical values of radial stress should now be compared with theory. While radial strains have received comment by previous authors,[6] and a formula applicable only to rectangular cross-sections is given by Föppl,[7] theoretical radial stress analysis of general application to curved beams apparently is not found in current engineering literature, and the following solution is submitted. Fig. 4 is a side elevation of a portion of a curved beam, such as Fig. 1, in which the plane of loading is a plane of symmetry.

[6] A. Lewis Jenkins, Trans. A.S.M.E., vol. 32 (1910), p. 320.
[7] August Föppl, Technische Mechanik, vol. 5 (1907), p. 75.

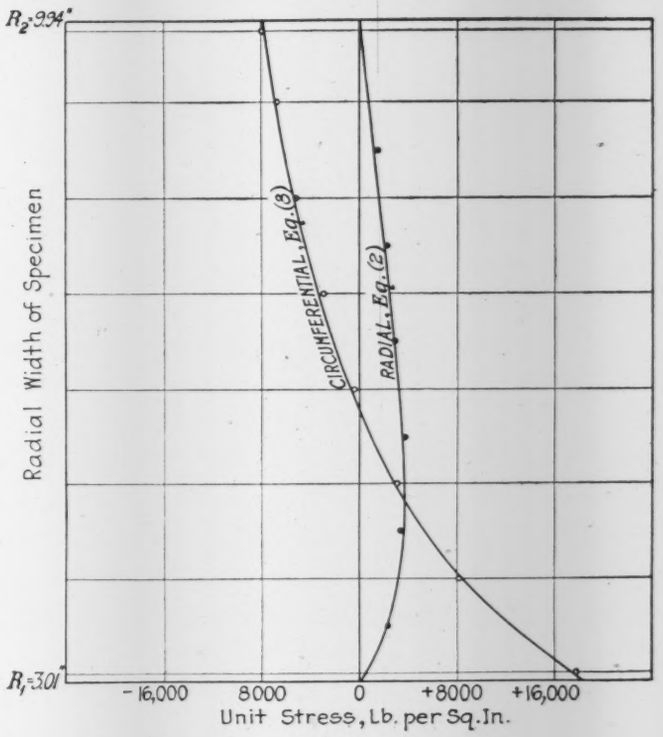

FIG. 6 CIRCUMFERENTIAL AND RADIAL STRESSES; SPECIMEN *A*. TEST RESULTS, INCLUDING EFFECT OF POISSON'S RATIO, COMPARED WITH THEORETICAL CURVES

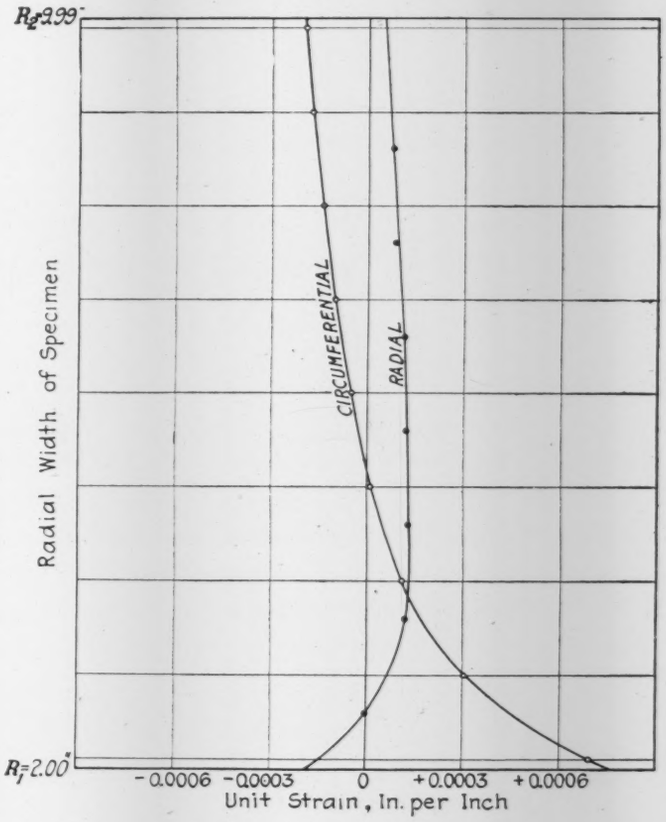

FIG. 7 CIRCUMFERENTIAL AND RADIAL STRAINS; SPECIMEN *B*. TEST VALUES WITH AVERAGE CURVES

In accordance with general considerations by previous investigators, discussion will be limited to the immediate vicinity of transverse plane OO' and it will be assumed that shearing stresses may be disregarded. The normal unit stresses C on plane OO' consist of the sum of stresses B due to bending and D direct, the latter over the total cross-section being equal to W, the external load.

Stress D, in direction of W, has no radial component, and the relation between the unit stress B and the radial unit stress T is readily derived by referring to Fig. 4. Heavy lines indicate a portion of the curved beam included between inner radius R_1 and intermediate radius R' and bounded by transverse radial planes subtending an infinitesimal angle $\delta\theta$. Let w denote width of cross-section at radius R; w in general is not constant. Then consideration of equilibrium of component stresses in a radial direction leads to the relation

$$T = \frac{1}{w'R'} \int_{R_1}^{R'} Bw\delta R \quad [2][8]$$

It is seen that the radial stress is tension throughout the cross-section, becoming zero at the surfaces R_1 and R_2. The integral in Equation [2] denotes the sum of the stresses due to bending on the cross-sectional area included between radius R' and the inner radius R_1. Moreover, this relation for radial unit stress is perfectly general and applies with any theoretical value of B, the circumferential stress due to bending. For a flanged section with a thin web, where w is small, T is correspondingly large and the consideration of radial stress is important. The determination of the numerical value of T by Equation [2] involves no special difficulty; the summation represented by the integral may be obtained readily either graphically with a planimeter or in many cases with sufficient accuracy by approximate numerical computation.

Theories of Circumferential Stress

The relation [2] for radial stress shows that the Andrews-Pearson formula, as a refinement of the Winkler theory, is erroneous and without value. The fundamental feature of the Andrews-Pearson formula is the additional consideration of changes in radial dimensions due to radial strain; it takes account, however, only of Poisson's lateral distortion due to circumferential stress and omits entirely any consideration of strains due directly to radial stress. These latter strains in certain shapes of cross-sections may be very large, and in a considerable portion of any cross-section are in a direction opposite to the Poisson lateral strains.

Consideration of radial stresses not only overthrows the Andrews-Pearson formula, but also renders Winkler's solution inconsistent with the original hypothesis that plane transverse sections remain plane after loading. The plane-section relation, in agreement with Winkler's theoretical circumferential strains, is destroyed by the added strains due to the Poisson effect of radial stresses. The hypothesis regarding plane sections seems to be pure assumption without theoretical proof. The principle of least work, however, is gaining increasing recognition as a logical starting point in stress analysis, and in the following portion of this paper an attempt is made to apply this principle to the problem of circumferential stresses in curved beams. The interdependent relation of radial and circumferential stresses makes the problem complex, and a direct analytical solution appears to be beyond the facilities of mathematics. However, a certain approximation leads to a definite solution showing important results when compared with Winkler's theory and with the present test observations. The application of the theory of least work to curved beams is simplified somewhat by the consideration, first, that in a straight bar of constant section subjected only to longitudinal stress the condition of least work is with the stress uniformly distributed over the cross-section. This is readily proved by simple applications of principles of equilibrium and of least work. From this result it follows that in a curved beam, Fig. 4, for least work the unit stress at any radius R is constant across the total width w of the cross-section. The considerations regarding neglect of shearing stresses are here the same as in the derivation of Equation [2]. Also, to reduce complexity for the time being, let the work due to radial stresses and strains be disregarded, so that the problem is limited to determining that distribution of circumferential stress which gives a minimum value for the work done by circumferential stress alone. In Fig. 4, referring to the elementary mass of radial dimension δR, the following three equations are obtained for vertical stress equilibrium, moment equilibrium, and least work, respectively:

$$\int_{R_1}^{R_2} Cw\delta R - W = 0 \quad [3]$$

$$\int_{R_1}^{R_2} C(R + s)w\delta R = 0 \quad [4]$$

$$\frac{\delta\theta}{2E} \int_{R_1}^{R_2} C^2 Rw\delta R = \text{minimum} \quad [5]$$

The three conditions may be gathered into one relation, as follows:

$$\int_{R_1}^{R_2} (K_1 C + K_2 CR + C^2 R)w\delta R = \text{minimum} \quad [6]$$

in which K_1 and K_2 are constants to be determined later. Making the derivative coefficient of Equation [6] with respect to C equal to zero,

$$K_1 + K_2 R + 2CR = 0$$

Since the second derivative is positive, this is the condition for a minimum, or

$$C = -\frac{K_1}{2R} - \frac{K_2}{2} \quad [7]$$

Substituting this value of C in Equations [3] and [4], solving for K_1 and K_2, and substituting in Equation [7], the final result is

$$C = \frac{M\left(\frac{1}{R} - \frac{1}{A}\int_{R_1}^{R_2} \frac{w\delta R}{R}\right)}{R_g \int_{R_1}^{R_2} \frac{w\delta R}{R} - A} + \frac{W}{A} \quad [8]$$

in which R_g is the radius to the gravity center of the cross-section, A is the area of the cross-section, and $M = W(s + R_g)$. This result, Equation [8], is identical with Winkler's formula; in other words, neglecting radial stresses and considering circumferential stresses only, Winkler's formula may be derived from the hypothesis of least work without resorting to the assumption that plane transverse sections remain plane after loading.[9] The question now arises concerning the extent to which the circumferential stresses are theoretically modified in the least-work hypothesis by including the radial stresses. This point may be contemplated with some approximate speculations, dependent on the fact that, at the place in the cross-section where the circumferential stress is a maximum, the radial stress is zero. A derivation similar to that used in Equations [3] to [7] inclusive, but taking complete account of radial and circumferential stresses, gave much longer and more complex expressions which it seems unnecessary to publish in full. The resulting relation, for reference designated as Equation [8′], corresponding to Equation [8], contained on the right-hand side certain terms having integrals involving C, thus not giving a direct solution for C. To determine, in a special case, the variation between the approximate solution, Equation [8], and the precise solution, computations were made for specimen A by the method of successive approximations. The final derived value of C, compared with the approximate solution, Equation [8], showed differences which were very slight and for practical purposes negligible. The above, of course, is only one special case, and too sweeping general conclusions should not be drawn from the result.

Comparisons of Tests with Theory

Adopting Winkler's Equation [8] as the most logical approximate solution at present available for circumferential stresses in curved beams, theoretical values of radial stresses are then obtained by Equation [2]. For specimen A, with test load, Equation [8] becomes

$$C = 19{,}430\left(\frac{5.80}{R} - 1\right) + 181 \quad [8A]$$

The term $19{,}430\left(\frac{5.80}{R} - 1\right)$ denotes the bending stress B. This value substituted in Equation [2] gives

[8] It is shown later that the element of area may be taken equal to $w\delta R$.

[9] Making R infinite reduces Equation [8] to the usual bending formula for straight beams, thus deriving the straight beam formula from the hypothesis of least work.

$$T = \frac{19{,}430}{R}(5.80 \log_e R - R - 3.38) \quad [2A]$$

For specimen B the corresponding results are

$$C = 14{,}150\left(\frac{4.968}{R} - 1\right) + 1273 \quad [8B]$$

$$T = \frac{14{,}150}{R}(4.968 \log_e R - R - 1.443) \quad [2B]$$

By the preceding equations, with the aid of Equations [1], the test observations comprised in this paper may be compared with

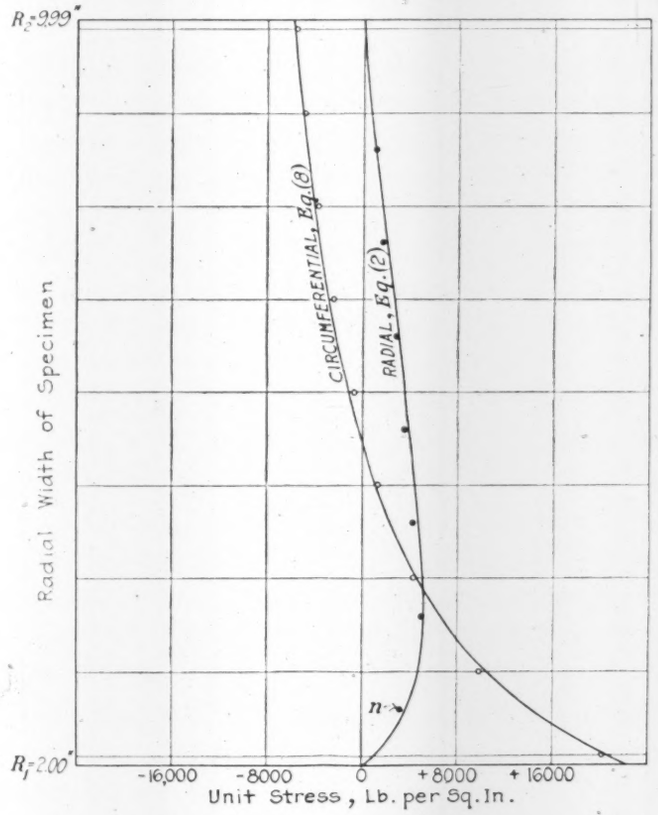

FIG. 8 CIRCUMFERENTIAL AND RADIAL STRESSES; SPECIMEN *B*. TEST RESULTS, INCLUDING EFFECT OF POISSON'S RATIO, COMPARED WITH THEORETICAL CURVES

the theoretical Equations [8] and [2]. This comparison is shown by Figs. 6 and 8, in which the curves are theoretical, while the plotted points represent test results. Few differences are found in excess of 0.04×10^4 lb. per sq. in., which is the stress corresponding to the smallest estimated interval used in strain-gage readings. These results therefore, for the specimens tested, appear to verify the theory of radial stress and to indicate the value of Winkler's formula as a sufficiently precise method of analysis for practical application.

A scrutiny of testing procedure reveals certain small approximations in method. For example, the circumferential strains were measured on a chord instead of on a circumferential arc; the lines on which the radial strains in specimen A were measured are not precisely radial; also the plotted radial strains are not the values at the points of plotting, but are the average values over a one-inch radial interval. This last consideration reduces the apparent discrepancy in places such as point n, Fig. 8, which correctly lies on the concave side of the theoretical curve. Each of the above approximations could be corrected, but the revisions would be very small; for simplicity and also in order to avoid the impression of any attempt to manipulate the observations toward more favorable results, the test values are plotted directly without these slight corrections.

Photoelastic investigations were also made with a celluloid model of specimen B. The radial location of the place where the circumferential strain was equal to the radial strain, determined by direct photographic record, agreed exactly with the result of the strain-gage observations on the steel specimen. The maximum tensile stress determined by photoelasticity checked the theoretical value computed from Equation [8] within five per cent, an agreement considered to be well within the range of precision of this method of testing.

CONCLUSIONS

As shown by theoretical analysis and by the limited number of test observations comprised in this paper, the following conclusions are indicated:

a In the design of curved beams radial stresses should be investigated, particularly in cases of flanged members with thin webs. For computing radial stresses, Equation [2] is proposed

b The Andrews-Pearson formula, as a refinement of the Winkler theory, is fundamentally incomplete and erroneous

c The adoption of the Winkler formula is recommended as the most logical approximate solution for circumferential stresses at present available

d Further tests of curved beams are desirable, comprising several different shapes of cross-sections.

Discussion[1]

CASPER D. MEALS[2] wrote that Bach, in his Elasticität und Festigkeit, had elaborated upon Winkler's earlier works, and presented formulas that would give the same results. Bach's theory was given in Greene's Structural Mechanics of 1911, the fundamental equation for the stress intensity being

$$f = \frac{W}{A} + \frac{M}{RA} + \frac{M}{KRA} \cdot \frac{y}{R + y} \quad [9]$$

where R = radius of curvature of neutral axis of critical cross-section

y = distance from neutral axis to fiber of section under consideration

$M = Wl$

$$K = 1/A \int \frac{y}{R + y} \delta A = \frac{A'}{A} - 1$$

A' = area of modified section $= R \int \frac{1}{R + y} \delta A.$

For hooks, rings, links, etc., failure was due to tensile stresses, hence for a hook loaded as shown in Fig. 1 the maximum tensile stress intensity was

$$C = \frac{W}{A} - \frac{Wl}{RA} + \frac{Wld_t}{KARR_1} \quad [10]$$

where d_t = distance from neutral axis to outermost fiber on inner or tensile side of section, and

$l = s + R$ = lever arm.

Where the line of application of load W coincided with origin O of R_1,

$$C = \frac{Wd_t}{KAR_1} \quad [11]$$

Maximum values of C were as follows:

Wrought-iron hooks	20,000 to 25,000 lb. per sq. n.
Hammered steel hooks:	
0.10 to 0.25 carbon steel	25,000 to 30,000 lb. per sq. n.
0.30 to 0.40 carbon steel	30,000 to 36,000 lb. per sq. n.
Drop-forged steel hooks:	
0.30 to 0.40 carbon steel	36,000 to 42,000 lb. per sq. n.
Cast-steel hooks of 0.15 to 0.25 carbon steel	same values as for wrought-iron hooks

An analysis of commercial hooks, crane or hoist, would show these seemingly excessive tensile stresses C. These, however, were the

[1] Abridged.

[2] Wire Rope Engineer, American Cable Co., New York, N. Y.

extreme fiber stresses. The adjoining fibers, and those nearer the neutral axis, were subject to but little stress in comparison, and the conclusion drawn was that the extreme fibers were assisted in sustaining their maximum stresses by the large mass of adjoining fibers subject to lower stresses, and also that any slight bending of the curved beam resulted in some readjustment of the forces which tended to reduce the moments below the calculated values.

A. K. Pedersen[3] in an article on the design of eyebolts and lifting eyes, using Equation [9], had noted the seemingly excessive values of C and accordingly proposed a "correction factor" of 2.20, so that the theory and practice could be reconciled. Compared to values of C above, this factor gave $30{,}000/2.2 = 13{,}650$ lb. per sq. in., a more reasonable fiber stress. It was, of course, a rather quieting artifice for those skeptical of higher values, but the results were identical.

An analysis of chain links by Equation [9] led to the same high values of C, even for loads of $W = 10{,}000d^2$.

Formulas [9], [10], and [11] had been used by Mr. Meals for a number of years in the designing of hooks, rings, eyebolts, links and small open frames for plate-lifting clamps, all of steel.

As to their adaptability to large press and punch frames of cast iron, Equation [9] should be applicable, but lacking experience in the design of such members, some hesitancy was felt in recommending values of C for this purpose.

S. Timoshenko[4] wrote that the purpose of the paper had apparently been to compare the stresses as obtained by experiment in curved bars with those computed on the basis of the usual theory of curved bars as developed by Winkler. It seemed, however, that the authors of the paper were not aware that for the case of curved bars of rectangular cross-section an exact solution of the problem existed, which was based on the integration of differential equations of the theory of elasticity. This exact solution had been obtained by Prof. H. Golovin as long ago as 1880.[5] It had been published in Russian and remained unknown in other countries. At a later date, however, the same problem had been solved by Prof. L. Prandtl of Göttingen, and this solution could now be found in the various books on the theory of elasticity.[6]

Due to the discrepancy between the exact formula and Winkler's approximate formula for circumferential stresses there would be also a difference between the radial stresses. Correct values for these latter stresses would be somewhat less than as calculated in the paper. The exact solution of the problem showed also that in the case of pure bending the cross-sections of the curved bar remained plane during bending, as Winkler had assumed in developing his approximate theory. The error of this theory was due to the fact that the radial stresses had been neglected. The exact theory mentioned above showed that the effect of these stresses was small and that Winkler's theory was accurate enough for practical application.

The authors claimed that by using the principle of least work "a more logical fundamental hypothesis was advanced in support of the theory adopted," but in their development the radial stresses were neglected, which made their result as approximate as that obtained by Winkler.

In order to get satisfactory results, both circumferential and radial stresses had to be taken into consideration and this could be done without difficulty.

Referring to the experimental part of the work Dr. Timoshenko did not agree with the authors that previous laboratory tests had been, in general, of meager scope and uncertain interpretation. It was true that by observing the apparent proportional limit of curved specimens in bending, only a very rough comparison of test with theory could be obtained; but there had been tests in which very careful measurements of strain during bending were made with much more accurate measuring instruments[7] than the strain gage used by the authors.

The error of the strain gage used was, as stated in the paper, about 0.000015 in. per in., and with this instrument such small radial strains as 0.000025 to 0.000119 in bending tests, and such lateral contractions as 0.0000546 in tensile tests had been measured. It was clearly seen that not only third but also second and sometimes the first figures in these readings could be affected by errors in measurements. For instance, Poisson's ratio, given as equal to 0.255, could be equal also to 0.29 or 0.30 as it was usually taken for mild steel and as it had been obtained by more careful experiments.[8]

Dirk Dekker[9] wrote that the close agreement of results obtained analytically with those obtained experimentally proved the worth of the authors' work. He suggested a way which he believed would better present the unit stress C on area wdr.

F. N. Menefee[10] wrote that in the development of the elastic theory, from time to time, we had made certain assumptions which might have been accurate enough for the original case at hand, but which later had found their way into places where they were positively dangerous. Strain-gage, photoelastic, or other methods for accurately determining strain or, at least, relative deformation, were being developed so rapidly now that one was hardly justified in attempting to develop stress formulas without the check of the gage, or even in preceding the development of formulas by determining the strain.

The investigation of the authors was a good illustration of this point, and should be followed by others on other types of bent beams and on planes differing from the one they chose, for it might be that there was a compounding of stress on some diagonal plane, which was greater than on plane $O'O$, Fig. 1.

Little by little we were reducing our assumptions by more exact information furnished by the strain gage. The assumption that the curved beams in question were isotropic was an incorrect one, but probably was well within the limits of our knowledge of E for the material.

Two very vital factors that engineers often overlooked in the development of stress theory were: (*a*) lack of knowledge of E for the material within five per cent, and (*b*) the impossibility of the assumed conditions to be realized in practice.

Concerning the first, in calibrating a strain gage to be used in determining the strains in an important bridge, a report, "accurate to within one-half of one per cent," had caused great anxiety until a conference could be arranged and the client reminded of the use of the value of E, which he had been assuming to be 30,000,000.

Of the second factor, Professor Menefee had recently conducted tests on columns and beams in a structure designed and built to support a generator, condenser, and steam turbine in a large steam plant. Measurements had been made just after erection, after the concrete mat had been laid, and again after the units had been set. A complete study of the data led to the conviction that not a beam nor a column was stressed in the way and amount that the designer had intended. He felt that this condition in our structural field was fairly general, and probably arose from the fact that we made assumptions regarding the application of load which never could be realized. Too often we forgot that the reaction at the end of a beam was a load, and that the end connections had as important a part in the stress functioning of the beam as the way in which the live load was placed.

A. L. Kimball[11] wrote that the matter of radial or transverse stresses brought out by the authors was very nicely shown in the photoelastic method of analysis. In fact, this problem was one which lent itself beautifully to that method of analysis. In such experience with that method as he had had, an interesting feature had been the presence of the transverse stresses mentioned by the authors where they would not always be expected. For accurate analysis of complex shapes or irregular shapes, account should be taken of such stresses. The problem as given by the authors should be checked by the photoelastic method. It was not meant that the results as stated were not correct, but that the photoelastic method should be used merely as a matter of getting an additional check.

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[3] *American Machinist*, May 18, 1911.

[4] Research Engineer, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa. Mem. A.S.M.E.

[5] See Bulletin of the Technological Inst. in St. Petersburg, 1880.

[6] See Encyklopädie der Math. Wissenschaften, vol. IV, 2, II, page 340. A. Föppl and L. Föppl, Drang und Zwang, vol. I (1924), page 303. S. Timoshenko, Theory of Elasticity, vol. I (1914), page 110.

[7] See Preuss, *Zeit. des Vereines deutscher Ingenieure*, 1911, or Mitteilungen über Forschungsarbeiten, no. 126.

[8] See paper by Williams, *Phil. Mag.*, 1912.

[9] Assistant Professor of Mechanical Engineering, Montana State College, Bozeman, Mont. Assoc-Mem. A.S.M.E.

[10] University of Michigan, Ann Arbor, Mich.

[11] Research Engineer, General Electric Co., Schenectady, N. Y. Assoc. A.S.M.E.

The authors in their closure said that Mr. Meals had contributed useful data on working stresses for crane hooks and had also stated several of the various forms in which Winkler's solution was given by different authors. As noted, by simple algebraic transformations each one of these solutions could be shown to be identical with Equation [8].

On several phases of the work of this paper Dr. Timoshenko had submitted discussions, which required definite replies. Much emphasis was placed on Golovin's solution, which had not been overlooked by the authors, as Footnote 7 of the paper referred directly to the complete derivations of the equations given by Dr. Timoshenko. At the beginning of the present tests, the authors had seen a statement of Golovin's formula for circumferential stress, together with the information that the formula was limited to bars of rectangular cross-section, but no further features of importance had been ascribed to it. Föppl's derivations had been subjected to careful scrutiny, leading to the conclusion that Golovin's formulas were so exceedingly limited in application that it was appropriate to cover them simply by a footnote reference without detracting from the continuity of the paper by extraneous discussion. The comments by Dr. Timoshenko, however, now made it necessary to point out the limitations of these formulas. This could be done by giving their derivation in brief outline, together with a more complete statement of the authors' solution by successive substitutions, which apparently had been overlooked or misunderstood by Dr. Timoshenko. [The derivations follow here in the complete discussion—EDITOR.]

In order to obtain a complete mathematical solution, Golovin had assumed the condition of pure bending. The word "never" might be challenged, but a curved beam subjected to pure bending without direct stress was at least very rarely encountered in practice. The question now arose whether this exact solution derived for the condition of pure bending applied also to the usual condition of bending combined with direct stress. Golovin's exact solution appeared to be mainly of mathematical interest, practically without application to actual cases of curved beams. While it might be argued that the approximation obtained by Golovin's solution was small, the same might be said for Winkler's formula; for example, with pure bending, and $R_2/R_1 = 3$, the two formulas gave a difference in maximum stress of only about 0.6 per cent, according to the authors' computations, instead of 6 per cent as noted by Dr. Timoshenko. As Golovin's solution was also limited completely to rectangular cross-sections, it had seemed appropriate to refer to it only by footnote, and to devote more complete consideration to Winkler's formula, which had general application to various shapes of cross-sections.

As superior in accuracy to the present tests, Dr. Timoshenko had cited a single example, the work of E. Preuss. These tests, which had not previously come to the attention of the authors, consisted of measurements of circumferential strains at several radial positions on two crane hooks of 5 tons and 10 tons capacity. While the authors had no desire to disparage these interesting and important tests, a statement should be made regarding the precision attained. Four sets of measurements had been taken; for the value of maximum tension one test had shown a difference between test and theory of 5.5 per cent, and the other three tests had shown differences varying from 25.1 to 33.7 per cent. For the maximum compression the difference between test and theory had varied from 14.2 to 22.2 per cent. In view of the large variations from theoretical values obtained by Preuss, it seemed unnecessary to discuss the accuracy of the strain gage, a mirror extensometer of modified Martens type used on an interval of 10 mm.

In spite of comments in the paper regarding the unimportant effect of a small change in the value of Poisson's ratio, Dr. Timoshenko had criticised the magnitude of the measurements used for lateral strain. This criticism was the result of a misunderstanding due to the fact that the log of these tests had not been published in full. For determining Poisson's ratio in bar A, the original log showed that the loads used had varied slightly from a minimum of about 3000 lb. to a maximum of about 31,000 lb., giving a load increment of about 28,000 lb. To obtain comparable results, each reading had been reduced to the equivalent value at a load of 10,000 lb., or 6420 lb. per sq. in. Without thought of creating false impressions, these reduced results had been published, and the misapprehension that had been caused thereby was regretted by the authors. The actual loads had been nearly three times 6420 lb. per sq. in.; also the strain interval in this case had been 2 in., giving a precision practically six times as good as that noted by Dr. Timoshenko.

The discussion by Professor Menefee considered stresses in portions of the curved beams not investigated by the authors. Information relative to these stresses could be obtained by the photoelastic method, and present plans of the authors contemplated these more comprehensive photoelastic investigations. This statement, together with the results noted in the paragraph of the paper preceding the conclusions, also constituted a reply to the discussion by Mr. Kimball.

In conclusion, it seemed desirable to mention one result of the present tests which had not yet been noted. Several previous authors, in discussing curved beams, had referred to the possible effect on stress distribution caused by the proximity of the applied load. No appreciable evidence of this effect was shown by the test results for specimen B, which was a curved beam of sharp curvature and short load leverage.

Testing of Welded Joints—A Preliminary Plan of Research

BY EUGENE JACOBSON,[1] SAN FRANCISCO, CAL.

IT IS desired to formulate a test for the soundness of welded joints, which may be applied to every joint made instead of merely to isolated test specimens. In surveying the possible test media, light, X-ray, and similar visual indications of unsoundness of weld have been discarded because of the opaqueness of the metals. Electrical conductivity of the weld as a test of its homogeneity offers considerable possibility in the case of welded rods, tubes, and similar small regular sections, but presents serious difficulties in the case of large and irregular sections such as flat plates, beams, and the like.

Sound, or more broadly, vibration transmissibility as a test of soundness of the joint offers certain interesting possibilities. It is well known that a tight bearing sounds differently from a loose bearing when tapped with a hammer. It takes but a slight alteration in structure to cause a marked change in vibrational characteristics. It is reasonable to assume that a tight homogeneous joint would have different vibrational or sounding characteristics than a joint that was porous or poorly bonded. Whether the difference would be detectable by the human ear is questionable, but there is little doubt that a vibroscope would detect these differences. Comparing a joint which is only 50 per cent bonded to a perfect joint, it is reasonable to suppose that the two would transmit vibrations of different amplitude, and perhaps of different wave form, duration, and frequency as well, in response to a given measured hammer blow.

The method would find its initial application in the testing of standard parts produced in large quantities. A joint known to be poor would be submitted to the vibration test together with a joint in exactly similar bodies which was thought to be good. The two joints would then be subjected to confirming tests "to destruction," and the ultimate strengths would be compared to the vibrograph charts. In this way it would be possible to isolate certain vibrational characteristics of the poor joint which should, over a period of such test experience, become reliable to far more than the fifty per cent accuracy of strength indication expected of them.

It is anticipated, of course, that hammer blows will be applied longitudinally and transversely of the joint on one side thereof, and that the vibration will be measured on the other side of the joint; preferably, but not necessarily, quite close to the weld.

[1] 535 Stockton St. Jun. A.S.M.E.

Drilling- and Pumping-Rig Equipment

Discussion of Various Methods, with Comparative Estimates of Cost, of Changing Standard Oil-Well Rig to Improve Its Operation

By GLENVER McCONNELL,[1] TULSA, OKLA.

STANDARD drilling- and pumping-rig equipment has always been one and the same thing. Rotary drilling requires an equipment entirely different from that used for cable tools on standard rigs. This paper is intended to focus attention on equipment which is used when a well is standardized.

All standard-tool drilling and all heavy-duty pumping equipments consist primarily of a walking beam operated by a crankshaft and pitman with means provided for operating hoisting apparatus. Any suitable prime mover may be used. The idea is basically very old and will be replaced with difficulty.

The application of this principle in the oil fields necessitated the early development of a specially built, quickly reversible steam engine, which could be belted directly to a band wheel on the walking-beam crankshaft. Many years later special electric induction motors, either for single or double speed and horsepower range were developed, ostensibly to replace the steam engine. Oil-field gas engines were likewise introduced for the same purpose, but they are substituted chiefly for standard pumping duty. Very recently the industry has adopted to some extent the use of high-speed multiple-cylinder gasoline motors using natural gas as a substitute cheap fuel, and the Diesel engine is now making its appearance. These last two types of engines will provide a choice of unit interchangeable in speed characteristics with electric motors, offering suitable power and many economies over steam.

Many think the old idea of a large band wheel belted directly to the power unit is soon to be a thing of the past. It has been retained so long because it possesses simplicity and is universally applicable for use with any engine. Its mechanical efficiency has been generally ignored, but now that there is greater necessity than ever before for reducing power-transmission losses and operating expense, new ideas of rig equipment, particularly for pumping, are being developed. Certain fundamentals that will have a bearing upon the trend of improvement of such time-honored equipment should therefore be considered.

Rig Improvement Started with Pumping Equipment

Improvements in oil-well rigs started with trials of special attachments to provide long strokes for pumps handling large quantities of fluid and designed for use on standard rig equipment. These failed to accomplish satisfactory results, and were followed by specially built pumping units quite unlike any of the old standard rigs. The worm-geared crankshaft, and later, many double-reduction-geared crankshafts, found speedy application in areas where wells were completed entirely by the rotary method of drilling, and where the cleaning-out operation was largely confined to infrequent bailing and swabbing. Hydraulic-piston-operated pumps and special geared pumping jacks were designed. Some of these have met with considerable success; but, in areas where cable tools are used extensively, the widespread use of these forms of special equipment has not taken place so rapidly as it did in the all-rotary areas.

Today the industry faces three alternatives: (1) Adopt a dual system, in which the present standard rig equipment is used for drilling only and is then replaced by special pumping and hoisting equipment; (2) enlarge all parts of the standard equipment to permit the use of larger belts, better engine speeds, longer crank strokes, and better pulley ratios, and keep this equipment permanently in place for all future purposes; and (3) develop an improved drilling and pumping equipment that overcomes the limitations of both the standard rig now used and most of the special designs of pumping units. This equipment must be capable of speedy conversion from one requirement to the other.

It is highly important to plan carefully, because it is not reasonable to suppose that the gas-lift method of raising the fluid will obviate the final necessity of pumping. The economic limit of the gas lift cannot be established until more economies are perfected in the mechanical layout of rig equipment.

Essentials of the Cable-Tool or Standard Equipment

The essentials of a suitable rig equipment for permanent usefulness at wells where heavy loads are encountered and where drilling motions may at any time be needed for fishing, cleaning out, etc., are as follows: (1) Drilling conditions require

Full-load speed of crankshaft, 70 to 80 r.p.m.
Full-load speed of sand reel, 180 to 200 r.p.m.
Full-load speed of calf wheel, 10 to 35 r.p.m.
Full-load speed of bull wheel, 65 to 70 r. p.m.;

(2) Maximum horsepower demand at maximum speeds may be as high as 150, and at extremely slow speeds, 50 to 100 per cent of the horsepower required at full speed; (3) Rapid reversal of rotation at full load is necessary, and, whenever possible, it is advantageous to have 30 per cent faster reverse speed than forward; (4) All hoists handling large coils of rope should be in alignment with the center line of crank and well. Diameters of hoists for large-diameter rope should be not less than 18 in., and larger if possible; (5) For crankshaft power-transmission belts, gears or chains may be used, provided the layout permits placing the prime mover safe from fire hazard and includes means for transmitting reasonably full power to all machinery; (6) The prime mover must satisfy power requirements at all speeds; and must accelerate and decelerate promptly when the crank carries no counterweight to equalize well load of walking beam. The selection of gas engines should be based on accurate horsepower tests, with 25 to 40 per cent additional horsepower allowed to give long service and to obtain slow pick-up of dead loads by means of throw-in clutch; (7) The full complement of equipment must be adaptable to spud, drill, swab, lower, and hoist casing and tubing, to "jar" a string of tools that are stuck in the hole, and to pump a well of any depth that can be pumped, with a maximum stroke of 72 in., at a speed of from 12 to 30 strokes per minute; (8) In so far as it is possible, all items of the equipment should be of adequate size, quality, and workmanship to satisfy the accepted standards of proper application of the power to be used; (9) It should be easy to replace parts and to repair speedily in the field.

Limitations of Usual Standard Equipment

Cable-tool drilling derricks and derricks of short height used to replace rotary derricks have generally a base twenty feet square. To crowd into one corner of the derrick a calf wheel with bearings 6 ft. 6 in. apart it is necessary to set the front and back jack posts supporting the bearings of the band-wheel crankshaft not further apart than 4 ft. 4 in. center to center, as otherwise the drive sprocket on the outer end of the crankshaft used to drive the calf wheel will not be in alignment. In order to use standard makes of chain-driven sand reels, a minimum space of 15 in. from the inside edge of front jack-post bearing to the outside flange hub of the band wheel must be allowed to accommodate sand-reel clutch and drive-sprocket attachment. This limits the width of the band wheel to 14 in.

Belts 12 and 14 in. wide are not large enough for the heavy loads they must transmit at very slow speeds, frequently not over 600 ft. per min. and in increasing the width of the band-wheel face, the diameter must likewise be increased so that the drive pulley may be not less than 22 in. in diameter. This in turn calls for longer and better crankshafts, better bearings and supports, a derrick base wider than the twenty-foot standard, and higher elevation of some machinery supports.

When drilling a well with a steam engine, more favorable belt speed and arc of contact are obtainable, and it is generally after

[1] Roxana Petroleum Corp. Mem. A.S.M.E.

Contributed by the Petroleum Division and presented at the Kansas City Meeting, Kansas City, Mo., April 4 to 6, 1927, of The American Society of Mechanical Engineers.

the drilling is over and a gas engine is substituted that the belt troubles become most aggravating. This leads to the development of a special pumping unit and some special hoists.

SPECIAL PUMPING AND HOISTING UNITS

Two principal methods for economical pumping have come into much favor within the last three years. One embodies the use of a direct-geared crankshaft with gears completely enclosed and massive enough to carry heavy loads. The other is a set of hydraulically operated pistons used to raise and lower the sucker rods for extremely long strokes at any desirable motion.

The hydraulic apparatus is limited to actuating the pump, and aside from a smoothness of reciprocating motion obtained it possesses no mechanical advantage over the use of a carefully manipulated walking beam. For taking care of hoisting and well work the usual standard rig equipment is left in place and the same engine is used to operate the hydraulic pumps. Belt loads are still excessive, generally, and the space around the well is necessarily somewhat crowded.

REDUCTION-GEARED RIG EQUIPMENT

Reduction-geared units are generally used only for pumping, hoisting rods and tubing, and bailing. They are now being tried for drilling in small-diameter holes at depths where motion of beam is not likely to be very fast. To arrange a complete drilling layout it is necessary to use an expensive hoist in lieu of the standard calf wheel; to make special provisions for operating the standard bull wheel by means of a chain drive across the derrick floor from the calf wheel; and, to provide the latter with a countershaft, generally with two-speed sprockets, which must be driven by a chain from the out-board end of main crankshaft. The present sand reel in some cases may be used only where it is possible to true spooling alignment with the well hole. The revolutionary character of the equipment will necessitate, for drilling, the use of a prime mover that will run in one direction of rotation as readily as in the other and be instantly reversible. A long process of adjustment on the part of the operators to install them properly and to learn how they operate will next be in order. Electric motors will likely be the only suitable power for all purposes.

Almost any desired gear reduction is possible. A satisfactory reduction for use with a 75-hp. drilling motor will be somewhere between eleven and twelve to one. When adjusted for pumping this will have to be changed if the speed of the pumping motor is different. Likewise the sprocket ratio of any drilling-rig hoist that is left permanently in place will likely need to be changed.

"UNIVERSAL" RIG MACHINE FOR DRILLING AND PUMPING RIG

Realizing the limitations and the advantages of the usual standard equipment, the author has undertaken the development of a layout that will combine the advantages of the special pumping-unit idea and the geared unit, with all and more than one can obtain with either the present-size standard equipment or any of larger dimensions. The questions of costs, which are to be considered later, was one thing that prompted this undertaking, for it cannot be lightly dismissed in favor of high degrees of mechanical efficiency. Too great a departure from slowly improved standard equipment was thought to be unwise.

Referring to Fig. 1, the plan calls for steel-supported bearings for standard 6-in. crankshaft with a six-hole crank, using regular American Petroleum Institute front and back jack-post bearings, placed the usual distance apart. Instead of using a band wheel for belt drive, there has been substituted a large sprocket gear driven by a suitable roller chain capable of transmitting ample horsepower with the usual safety factor multiplied by four when reciprocating loads are encountered. At a convenient distance from this sprocket there is also on the crankshaft a special double-grooved tug wheel serving the dual purpose firstly, while drilling, cleaning out and fishing, of driving the bull wheels and secondly, when drilling operations are over, of carrying a specially designed adjustable counterbalance on the perimeter of the wheel to equalize the pump load. On the outer end of the crankshaft extension is the usual standard calf-wheel sprocket and clutch.

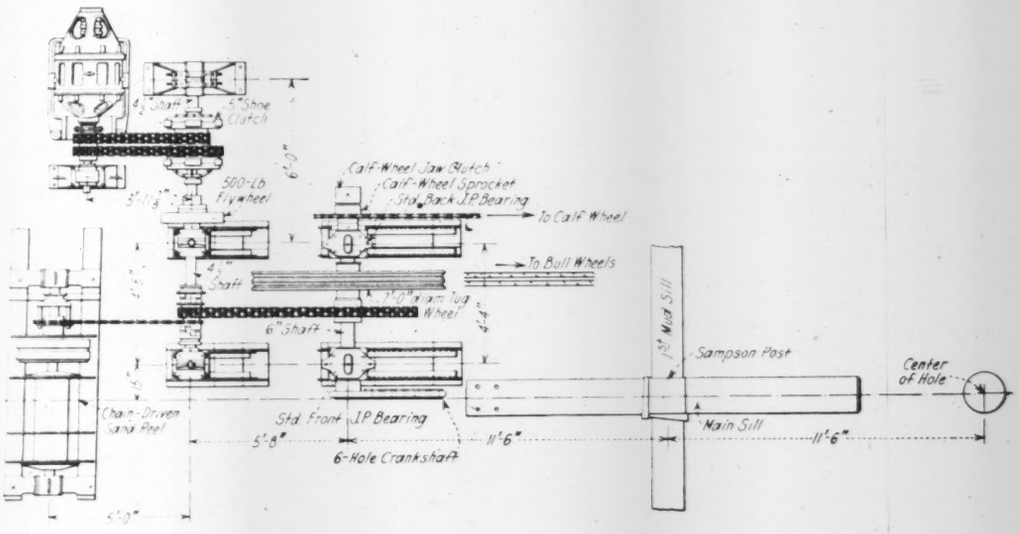

FIG. 1 LAYOUT OF UNIVERSAL DRILLING MACHINE DRIVEN BY ELECTRIC MOTOR

THE INTERMEDIATE SHAFT

To accomplish a double reduction and to serve many divers purposes, an intermediate shaft is paralleled with the crankshaft at a distance of about 5 ft. 6 in. center to center, on which is mounted a clutch-operated drive sprocket serving as the main drive. Next to this is another clutch-operated roller-chain sprocket serving as a driver for any standard chain-driven sand reel supplied with a driven sprocket of suitable dimensions. An extension of the intermediate shaft carries a small flywheel which serves as a neutral brake drum if needed. This much of the intermediate is coupled with the remainder of the shafting used by means of standard American Petroleum Institute flanges.

The driven end of the intermediate shaft may carry: (1) A two-speed sprocket transmission operated by friction clutches controlled by one lever extension to the derrick floor; (2) A plain belt pulley, particularly when a steam engine is desired for the power unit; (3) A clutch-operated reversible shaft—which would grant the opportunity of using any suitable oil-field engine without the troublesome outboard-bearing attachment now used for its reversible pulley; (4) Belt pulleys in case belt drives are wanted instead of high-speed roller chains.

ADVANTAGES OF THE "UNIVERSAL" RIG MACHINE

The advantages of the universal rig machine are as follows: Speeds for all requirements are easy to attain. Two speeds forward and two speeds reverse will meet with instant approval of field operators.

The operating efficiency may be as high as the most expensive geared units will attain if high-speed bearings are used. One should expect 75 to 85 per cent delivered to crank take-off, compared to 35 to 45 per cent for the usual standard rig.

Upkeep should be $50 to $100 per month less than with standard equipment, and depreciation greatly reduced. The power-unit upkeep will be also greatly reduced. Outboard clutch pulleys, so troublesome on engines, may be entirely eliminated.

The cost of power will depend upon what is used, but it is certain to be much less for any type selected for operating this unit. Two-speed electric motors will not be required and the practical possibility of using electric motors generally will become more nearly proved. Gas-engine power will be more practical for all classes of work than it has ever been with any other rig equipment.

TABLE 1 COMPARATIVE ESTIMATES OF COST FOR RIG EQUIPMENT (MACHINERY) INSTALLED TO DRILL WELL WITH CABLE TOOLS AND RE-EQUIP FOR HEAVY PUMPING BY SELECTED METHODS (WALKS, PLATFORMS, AND DERRICKS ARE OMITTED—MACHINERY HOUSE INCLUDED)

Types of power	Old			First				Second				Third				(A)			(B)
	Present equipment for drilling with wood machinery supports, steel bull- and calf-wheel posts and steel wheels, 14-in. drilling belt, etc., and equipping pumper with concrete base for engine, 3600-lb. equalizer on band wheel, and leaving bull wheel in place.			Dual system (for heavy load), using standard drilling equipment as before, replacing for pumping with geared crank unit with counterbalanced crank and special hoist in derrick.				Using enlarged standard rig layout with steel jack posts on concrete base, 14-ft. diameter band wheel with 18-in. face, 6-hole crank, 18-in. belting and extra-heavy equipment in steel housing.				Using special geared crank unit and special hoists throughout, but salvaging drilling rig hoists when used for pumping, and substituting special two-speed tubing hoists.				Using universal drilling- and pumping-rig equipment.	
	Cost for driller	Converted to light pumper using 40/80-hp. oil-field gas engine	Pump'g with electric motor 20/50-hp.	Cost for driller	Pumper direct connected with 70-hp. multi-cyl. gas engine with reverse	Pumper direct connected with 20/50-hp. electric motor	Pumper belted to 40/80-hp. oil-field gas engine with reverse	Cost for driller	Converted to pumper—3600-lb. equalizer, using 40/80-hp. gas eng., 22-in. diam. pulley	Converted to pumper—50/100-hp. gas eng., band wheel, counterbalance etc.	Using 20/50-hp. electric motor and countershaft	Cost for driller not applicable at present	Converted to pumper using 20/50-hp. motor	Cost for driller	Pumper using same prime mover	Pumper using 40/80-hp. gas engine two-speed	Pumper using 30-hp. slip-ring motor two-speed	Pumper, 70-hp. multi-cylinder gas engine with reverse
With 12 x 12 steam engine, 50-hp. boiler, turbine light plant; no outside lines	Investment	10600	10200		16000	15700	16500		11800	13000	11900		14700				13200	11600	
	Salvage	3600	3600		5100	5100	5100		3600	3600	3600		5400				3600	3600	
	Net invest.	7000	6600	7100	10900	10600	11400	8800	8200	9400	8300		9300	9000	(Single-speed)	9100	9600	8000	9000
Electricity, 75-hp. motor, countershaft, controllers, etc.; no outside wiring	Investment	10700	9670			15000													
	Salvage	3700	3400			4600													
	Net invest.	7000	6270	7300	.....	10400	.....	8700	.....	.....	7300	12300	Not applicable at present	8300	Two-speed	11000	Two-speed	10200	Two-speed
Multi-cylinder gasoline engines, 120-hp.; special electric-light plant	Investment	13900	13500		19400	19100	19900		15000	16200	15600			700				3000	
	Salvage	6000	6000		6500	6500	6500		6000	6000	6000			9300				7200	
	Net invest.	7900	7500	9100	12900	12600	13400	12000	9000	10200	9600				Two-speed	11000	Two-speed	12800	Two-speed
50/110-hp. oil-field gas engine; special electric-light plant	Investment	Using drilling engine to pump												11000		1600		4600	13100
	Salvage															9400		4800	4200
	Net invest.	8700	8000												Single-speed	10400		9600	8200
			.....					10500	.....	10800						1600			
										1300						8800			
										9500	.....			10400					

NOTE—"Investment" in each case represents the total capital expenditure for all rig equipment, including amount required to convert driller into pumper.

Special chain-driven hoisting drums may be used after the well is drilled, but it is contemplated to use the standard sand reel for a rod and tubing hoist. This will obviate the necessity of further use of both the calf wheel and bull wheel at the pumping well, except in case of extreme emergency.

Counterweights used while pumping need not be altered when it is desired to pull rods and tubing. A cut-off clutch stops the rotation of crankshaft as the sand reel is driven from the intermediate shaft. To start pumping again it is only necessary to attach the pitman to the crank, throw out the sand-reel clutch, and throw in the drive clutch for crank rotation.

Every part is easy to inspect and to replace or repair in the field. Much of the assembly is of standard equipment long familiar to the field men.

This equipment should operate the largest pumps or the most difficult pump loads ever attempted by any rig up to the present time.

As a drilling rig it can be set up almost as quickly as the present standard equipment, and in case a hole is lost by a bad fishing job, its position may be as readily shifted.

Alternative Methods from the Cost Point of View

If one could follow through a period of three to five years the total mechanical expense chargeable to rig equipment only, he would obtain sufficient evidence to warrant the expenditure of much additional capital investment for the initial layout. Unfortunately, too little effort is made in proper allocation of costs in many oil-company offices to guide the engineer in demanding more efficient rigs. Some idea of operating expense may be obtained from the following:

(1) *Belt Expense.* Thirty-six deep wells in one major field equipped with gas engines show an average length of service of 117.8 days for each belt used. This average is taken from 73 carefully prepared belt records. The cost per belt per day was \$1.57, and cost of lost production per belt per day was \$1.83, making a total average expense chargeable to each unit equal to \$3.40. In another set of records from fourteen wells, and involving 34 belts, the total expense averaged \$3.44 per belt per day.

(2) *Reverse-Clutch and Gas-Engine Expense.* Reversible clutches on gas engines show an expense, including loss of production chargeable to breakdowns, of from \$0.17 to \$0.22 per well per day. Engines, belts, and clutches taken altogether may cost as high as \$6 per well per day, not including fuel, lubrication, or any labor expenses.

Elimination of Slow-Speed Belts and Single-Speed Reduction from Prime Mover to Crankshaft vs. Larger Standard Equipment

Before one considers at length the advisability of using a standard rig with large-diameter driver and driven belt pulleys to accommodate speed requirements both for engine and for crankshaft and to provide the use of wide belts, it is necessary to take into consideration an overhead charge to cover the expense of belt inspectors and proper appliances for correct application and care of belting. Field workers alone cannot take proper care of high-grade belting. Driver pulleys of 22 in. minimum diameter and band wheels 14 ft. in diameter will call for better-lubricated bearings than are now generally used. A lubrication expert may have to be employed. For the rig, better alignment will be necessary; steel supports will be fundamental; and American Petroleum Institute rig irons should be much improved. Consequently, of the three alternatives which have been proposed as feasible methods to apply when planning equipment for deep wells, there will be many arguments available by proponents of any of the three methods. The final decision will generally be based, however, on the capital investment, simplicity of layout, and, finally, cost of operation.

CAPITAL INVESTMENT FOR RIG EQUIPMENT

In order to present some idea of the relative expenditure necessary to "rig-up" a well to be drilled with cable tools, which is assumed will be a heavy pumper later, so that the total cost of rig expenditure for both requirements may be compared when considering any of the three principal methods of procedure, estimates are presented in Table 1. It will be noticed that more capital investment will be necessary to provide any improvement over the standard rig.

The dual system is more expensive than any of the three proposed or contemplated layouts that provide for but slight changes to convert a driller into a pumper.

The enlarged standard rig, which retains the idea of belting a prime mover directly to the band wheel, is practically as expensive as the more efficient plans that provide for a double speed reduction with a possibility of requiring no belts at all.

The two-speed universal design is the most adaptable for all conditions of any heavy machine developed thus far.

CONCLUSIONS

1 Rig equipment should be so designed and arranged that all cable-tool operations may be taken care of without replacing anything but the prime mover when a "driller" is converted into a "pumper."

2 No more of the standard American Petroleum Institute equipment should be sacrificed than is absolutely necessary.

3 Belt-driven band wheels are not necessary and high-speed belting only should be included in future transmission equipment for either drilling or pumping rigs.

4 Geared-crankshaft equipment for drilling is limited to use with electric motors unless present designs are greatly altered.

5 Standardization will be aided and the oil industry will profit if rigs are capable of being driven by any choice of prime mover already in use.

6 Rig efficiency depends largely upon transmission equipment of careful design, to meet the conditions of service intended.

Commenting on the paper, Hollis P. Porter[2] said that it would be difficult to change the standard rig because it required skill to operate such a rig and operators were familiar with the standard type. He felt that this standard rig should be studied so as to improve it. It was possible that the author had dwelt on the standard rig more than was necessary inasmuch as rotary drilling was being applied to a greater extent to deep wells, and in such a case the drilling machinery was replaced by a suitable pumping outfit. There was a great tendency toward the use of electric units altogether, and manufacturers of drilling and other oil-well equipment realized that they must electrify their units. There was need for a gear set and transmission which could be applied to the horizontal slow-speed gas engine. Lee C. Moore[3] said that the development of a power unit was of vast importance.

Electrical Applications in the Petroleum Industry

Motors for Use on Different Types of Oil-Well Rigs, Their Characteristics and Comparative Costs

BY D. M. McCARGAR,[1] ST. LOUIS, MO.

THIS PAPER does not discuss the advantages and disadvantages of the use of electricity for the operation of oil wells or for other duties in the petroleum industry, but is confined to the application of motors to the different types of drives found in the industry.

Some years ago when power companies and electrical manufacturers went to the oil operator with proposals of electrification, they found derrick set-ups driven with gas or steam engines. The operators considered this type of prime mover as satisfactorily filling their requirements, and demanded electrical apparatus that would accomplish practically the same results as the steam or gas engine. The combination used comprised a belt-driven band wheel and a rope-driven hoist device, either bull or calf wheel, and there was a fixed ratio between the driving and the driven sheave. With this set-up and with fixed ratios between the prime movers and the band wheel (this ratio being arranged for pumping speed), it was necessary to speed up the prime mover in order to get sufficient hoisting speed.

Some of the first attempts at electrification with the electric motor were made with what is known as the Y-delta motor, this motor having two horsepower ratings but one definite synchronous speed.

It is obvious that with a ratio fixed for pumping, some mechanical change had to be made to get hoisting speed, and several schemes were tried to accomplish this result, one being the changing of pulleys, a small pulley being used for pumping operation and a larger one for pulling. The change of pulleys was not successful because at the time the attempts were made nothing was offered but solid-core pulleys, which would rust on the shaft. This increased the time required to effect a change, and very likely damage was done to both of the pulleys before the complete change was effected. This led to development of a motor with two definite speeds, and of course two horsepower ratings, which accomplished all the results desired in the operation of an oil well, but at the expense of good performance in the motor.

This motor has been built in several different ratings, two common ones at the present time being 15/35 hp. and 20/50 hp. It has been very successful from the operating standpoint on wells that were within its capacity; and on the old-type standard rig it is about the only type of motor that can be used successfully unless some mechanical changes are made on the rig design. The general assembly of the rig, however, has changed very materially since the first motors were introduced into the oil fields, and it now seems that the general trend is toward chain-driven hoist devices which eliminate the necessity of the two-speed motor. The following paragraphs explain the different types of motors that can be used on the different types of rig hook-ups. All the set-ups that are mentioned refer to those pumping on the beam.

TYPES OF RIG HOOK-UPS

The standard rig with belted band wheel, friction-driven sand reel, and rope-driven bull wheel has a fixed ratio between bull-wheel sheave and band-wheel sheave, and in order to get proper hoisting speed it is necessary to use the two-speed motor or make some mechanical changes in the rig, such as putting a sleeve or spool on the bull-wheel spindle or changing pulleys. The changing of pulleys was found objectionable in the early days. Two of the larger pulley manufacturers are now prepared to supply a quick-detachable pulley that can be changed in a few minutes, which will eliminate many of the objections formerly met.

It will also be found that the modern steel bull wheel is strong enough to carry a spool of larger diameter with which to obtain hoisting speed. Therefore, if either of the above mechanical changes is made, it will be found that a "single-variable-speed" reversible motor can be used. The mechanical arrangement of this set-up necessitates the reversal of the motor for every stand of tubing pulled out of the well and the disconnection or centering of the band wheel or crank counterbalance.

The standard rig, using calf wheel with chain drive for hoisting and chain-driven sand reel, is ideal for the double-rated single-variable-speed motor, as the hoisting speed depends on the ratio between the driving sprocket and the driven sprocket, which is

[1] Wagner Electric Corporation.

Contributed by the Petroleum Division and presented at the Kansas City Meeting, Kansas City, Mo., April 4 to 6, 1927, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[2] Production Engineer, Gypsy Oil Co., Tulsa, Okla. Mem. A.S.M.E.

[3] Lee C. Moore & Co., Tulsa, Okla.

readily adjusted in the first place to obtain the correct speed in feet per minute of the hoisting rope.

This method of hook-up requires that flywheels and counterbalances be disconnected during hoisting operation.

The use of the calf wheel for hoisting with positive chain drive should appeal to the operator as it is positive and much more efficient than the rope-drive method as used with the bull wheel.

The standard rig, with band wheel and with chain-driven friction-clutch tubing hoist is ideal from the hoisting point of view, and this type of rig will allow the use of even a simpler and better motor than the single-variable-speed motor. The use of a friction-clutch tubing hoist, eliminating a majority of the reverses necessary with the positively connected rigs described before, will also eliminate the line jolts that occur when a motor is reversed under load with the set-ups mentioned before.

Survey of the Inglewood and Baldwin Hill fields in the Los Angeles basin shows that two of the larger operators are using friction-clutch chain-driven tubing hoists for their pulling operations.

The use of the friction-clutch hoist will now make it possible to use a double-rated single-constant-speed motor for oil-well operation, as the acceleration of load is now done with the friction hoist and it is not necessary to reverse the motor for every stand of tubing or rods pulled. These motors are reversible under light- or no-load condition, which allows them to be reversed should the blocks hang up and not coast down. Where variable speed conditions are desired this type of rig would indicate the double-rated single-variable-speed motor.

So far rigs with band wheels have been mentioned, but nothing has been said of the method of drive or speed reduction incidental to reducing the motor speed to band-wheel speed. Lately there has been a decided tendency on the part of the machinery manufacturer to develop some sort of a gear device that would set directly under the pitman end of the walking beam and eliminate the belts or single-reduction gears that heretofore have been used. This is a decided step forward as it is obvious to any engineer that a gear unit can be so designed that the overall efficiency will far exceed that of a belt drive.

To the author's knowledge to date there have been developed seven different types of what would be called double-reduction-gear units, all of which have their merits, and, strange to relate, all have been developed along similar lines.

These gear units are arranged with a crank on the slow-speed shaft and a sprocket on the opposite side for chaining to either calf wheel or friction-clutch tubing hoist.

This type of connection to a beam well eliminates entirely the necessity of a two-speed motor, and if the calf wheel is used for hoisting for this type of gear unit, it is necessary to use a double-rated single-variable-speed motor with reversible control, and to disconnect or center counterbalance devices.

Where a friction-clutch tubing hoist is used, the double-rated single-constant-speed motor can be used with good results. This motor is capable of reversal under light- or no-load conditions, but cannot be used for reversal under load.

Several times mention has been made of the disconnection of counterbalance devices where the motor is reversed. Even the centering of these devices on a well that requires reversal of the motor for every stand of tubing or rods is bad practice because the flywheel effect or the stored energy of the balance has to be reversed every time the motor is reversed, which makes a higher peak on the electric supply line than with the motor alone.

It is obvious that the ideal condition would be to leave the flywheel or counterbalance device centered and do the hoisting by means of the tubing hoist. In this condition the flywheel effect would be a help instead of a detriment.

There has been one type of tubing hoist developed that has the friction reverse device incorporated in it, so that all that is necessary to be done is to step on a control pedal adjacent to the operator and start the drum in the reverse direction, should the blocks hang up.

There are over one hundred gear units, the property of one company, in operation in Texas and Arkansas, having double-rated single-constant-speed motors attached thereto. These outfits are all provided with mechanical reverse devices on the tubing hoist and are never reversed for the pulling operation.

COST OF EQUIPMENT

Taking the cost of a 20/50-hp. two-speed oil-well motor as 100 per cent and comparing the cost of the different motor equipments, using the 20/50-hp. rating as a basis, one would get the following:

Two-speed double-rated motor	100
20/50-hp. double-rated, single-variable-speed motor	74
20/50-hp. double-rated, single-constant-speed motor	33.5

The above comparison is based on equipment with air-brake control, and where the equipment is designed for explosion-proof service, the difference is decidedly more marked. A comparison of motor characteristics is given in Table 1.

It is well to note in passing that the most expensive motor is very complicated and has a very low inherent power factor and efficiency, while the least expensive motor has the highest performance and characteristics and has the lowest maintenance cost.

All of the above applications have taken into consideration the use on the well of a motor of sufficient size to do both the pumping and pulling operations, but it will be found that in some cases a small motor of sufficient size to pump the well only can be used with good results, the pulling operation being done with a gasoline tractor or a portable electric pulling device.

TABLE 1 COMPARISON OF DIFFERENT TYPES OF DOUBLE-RATED MOTORS

	Two-speed	Single-variable-speed	Constant-speed
Ratings	2	2	2
Number of synchronous speeds	2	1	1
Speed reduction by resistance, low ratings, per cent	50	50	None
Slip rings	6	3	None
Reversible	With load	With load	Without load
Efficiency, low rating, full load, per cent	77	85	90
Power factor, low-rating, full load, per cent	67	91	91

This type of installation has been used on the old standard rigs where a friction-clutch tubing hoist is not provided on the rig set-up for pulling.

One operator in Wyoming has over 1000 wells being operated with 5-hp. motors and uses a slip-ring motor geared to a single-drum hoist, all mounted on a truck which is readily portable, for the pulling operation.

It might be of interest to know that this operator originally planned to equip his wells with 15/35-hp. two-speed motors, but found that the use of the two-speed motor would introduce serious distribution-line troubles, owing to the extremely low power factor of the two-speed motor. They therefore adopted the single-rated-motor scheme and apparently have been quite successful with it.

Central powers formerly indicated the high-torque slip-ring motor for starting, or a squirrel-cage motor with a clutch, if the operator wanted to start his power without the necessity of unhooking shackle rods. Most of the powers were primarily designed for use of steam, gas, or oil engines, and the method of drive was based on the use of these prime movers.

It will be found that motors with sufficient torque (not slip-ring type) to start central powers with all shackle rods attached thereto can be procured.

Where the power companies demand high power factor on the user's line or impose a penalty in lieu thereof, the central power is an ideal drive for the synchronous induction motor of the Fynn-Weichsel type.

It was mentioned that the drives for central powers were primarily based on the use of oil or gas engines. It remained for a manufacturer in Pennsylvania to design a geared central power with a motor mounted thereon, thereby eliminating all belts. This power uses a high-torque motor and no clutch, although it was originally designed to be used with a friction clutch.

A number of small jacks, each having its own motor, will be found in operation around Bartlesville and Tulsa, the earlier ones being primarily designed for small-cylinder-gas-engine operation and reconverted for motor operation, but there have since been put on the market several types of jacks that were basically designed for electric motors.

Power requirements for jacks of this type run anywhere from $1\frac{1}{2}$ to 10 hp. A goodly number with $1\frac{1}{2}$-hp. motors will be found in operation in the Bradford and Duke Center fields in Pennsylvania.

Lubricating Oils from Coals

Method of Preparation of Lubricating Oil from Coal Oil and Report of Tests of Two Samples, One Distilled from Coal and the Other a Straight Mineral Oil

By HARALD NIELSEN[1] and STANLEY BAKER,[2] LONDON, ENGLAND

FROM time to time the important question of producing oil suitable for lubricating purposes from coal has been taken up for discussion from various sides. The main outcome of these discussions has been to create great confusion in the minds of the multitude. From some authoritative sources it is stated that the prospects are very slender indeed of its being successfully accomplished; again, from other equally authoritative sources it has been maintained that the production of such oils is perfectly easy.

Ridiculous as it may sound, there is a certain amount of truth in both statements. It all depends upon the angle from which the problem is approached. If the coals are being distilled by so-called external heat, the prospects of success are very slight, unless very low temperatures—below 400 to 420 deg. cent.—are employed and, what is of paramount importance, unless the oil vapors are removed from the coal charge in uniflow with the passage of the heat.

When so-called internal heat application is employed the problem is within reach of solution provided that the distillation of the raw coals is effected in such a way that the so-called overburden of the raw coal in the retort does not scrub out the oil vapors of the gases, so that continuous reëvaporation and condensation of the oils takes place in the retort itself. If this is the case, the oils are being subjected to severe cracking and the production of good lubricating oils is out of the question.

If, on the other hand, the oils are removed before condensation of the high-boiling fractions can take place in the retort, reëvaporation is prevented, and a good lubricating-oil base is assured by internal heat application.

The following description of the refining methods employed, as well as the physical properties of an oil produced by the "L.&N." method of coal distillation, is given. This description is followed by the complete report of the National Physical Laboratory, Teddington, on the behavior of the coal oil in comparison with a very well-known high-grade brand of straight mineral well oil, both oils being subjected to the same conditions.

The prospects of producing a high-grade lubricating oil from coals in this country are thereby confirmed.

Preparation of Lubricants from Shirebrook Bastard Cannel Coal Oil

The crude oil obtained from the coal was distilled, and the following fractions collected:

Deg. cent.	On anhydrous basis Per cent	Per cent
0–300	16.5	17.5
300–350	13.6	14.6
350–370	9.8	10.5
Above 370	41.7	45.0
Pitch	7.0	7.5
Water and loss	12.5	..
Loss	..	4.9

That portion of the distillate (45 per cent of the crude oil) boiling over 370 deg. cent. was then worked up for lubricating oils. The tar acids amounting to 20 per cent by volume were removed by caustic soda, and the resultant oil refined with 3 per cent sulphuric acid, by means of which treatments the oil was reduced to 70 per cent of its original volume, equal to 30 per cent of the crude anhydrous oil.

The refining was effected without any difficulty. The refined oil was then distilled, and the first 25 per cent added to the kerosene fraction. The remainder was passed through a filter press at about —5 deg. cent. and the paraffin wax extracted. A subsequent distillation of the wax-free oil gave lubricating oils of a rather dark red color and a marked green fluorescence. The yield of all grades of lubricants amounted to about 15 per cent of the original crude oil, of which not more than 4 per cent was spindle oil.

A medium oil was selected for frictional tests which had the following characteristics; and corresponding data of the straight mineral oil used for comparison are also given. (See Fig. 1.)

	"L.&N." Oil	Well Oil
Specific gravity	0.981[1]	0.901[2]
Flash point (closed), deg. fahr.	415	420
Viscosity at 70 deg. fahr., Redwood sec.	1525	898
Viscosity at 100 deg. fahr., Redwood sec.	421	
Viscosity at 140 deg. fahr., Redwood sec.	124	121
Viscosity at 200 deg. fahr., Redwood sec.	50	55

[1] 18 deg. cent.
[2] 17 deg. cent.

Report on Tests of Two Samples of Oil

These two oils were tested upon the journal-friction machine shown in Figs. 2 and 3. A bush of special phosphor bronze is run upon a mild-steel shaft and fed at a uniform rate with the oil under test. The oil is supplied to the lower or unloaded side of the bearing by means of a displacer driven through gearing by an electric motor. When necessary the journal can be heated internally by the specially constructed gas burner shown in Fig. 4. The temperature is observed by means of a thermojunction placed in a hole drilled nearly through the wall of the bush at or near the position of maximum pressure.

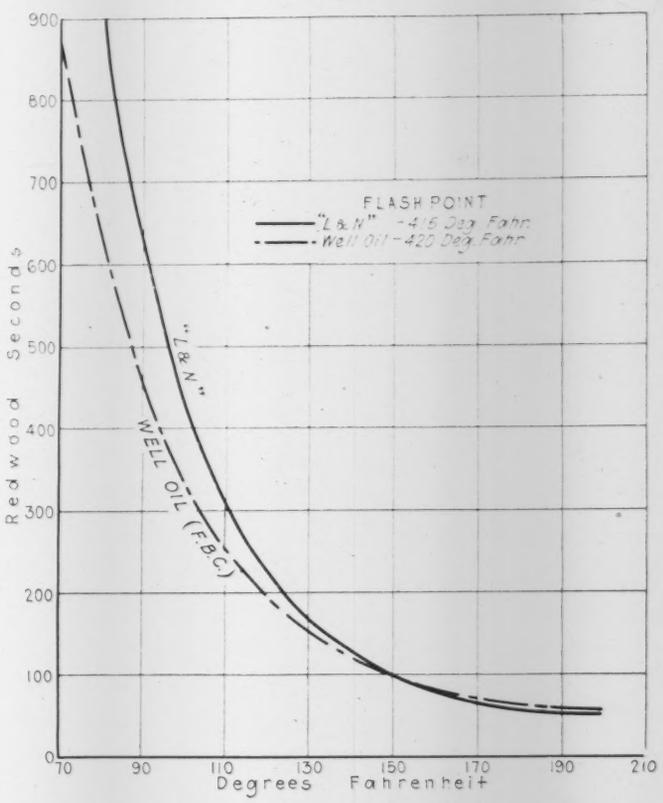

Fig. 1 Viscosity Curves

When a bearing of this kind is run it is found that the friction first falls as the temperature rises until a temperature of minimum friction is reached, after which an increase in friction occurs, and when a certain temperature is reached the friction increases rapidly and bush and journal finally seize together. This temperature is called the "seizing temperature." The bearing is not allowed to seize if it can be avoided, but as soon as the friction is seen to be

[1] Engineer and Technical Consultant, Sensible Heat Distillation, Ltd.
[2] Chief Chemist, Sensible Heat Distillation, Ltd.

rising rapidly the machine is stopped in order to avoid damage to journal and bush. In comparing oils by this method the two most important factors are (1) the minimum coefficient of friction, and (2) the seizing temperature. The latter appears to depend to a certain extent on density and viscosity, so that an oil may show

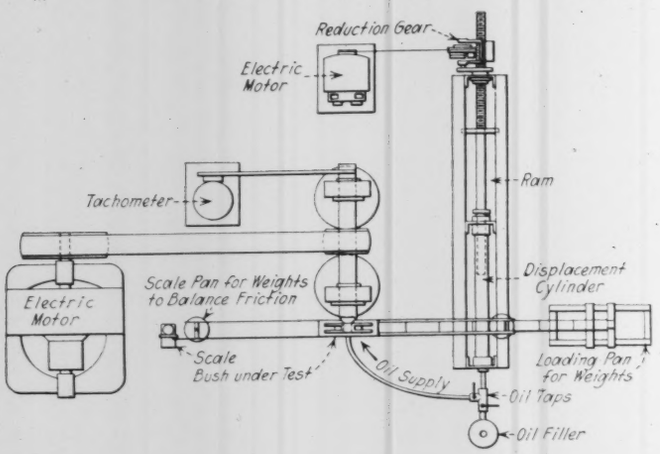

FIG. 2 ARRANGEMENT OF APPARATUS FOR FRICTION TEST ON LUBRICATED BUSHES

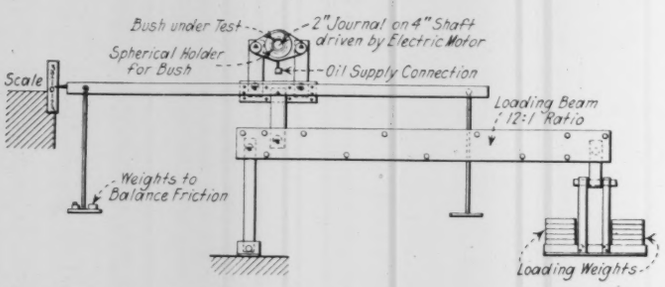

FIG. 3 GENERAL ARRANGEMENT OF APPARATUS FOR FRICTION TESTS ON LUBRICATED BUSHES

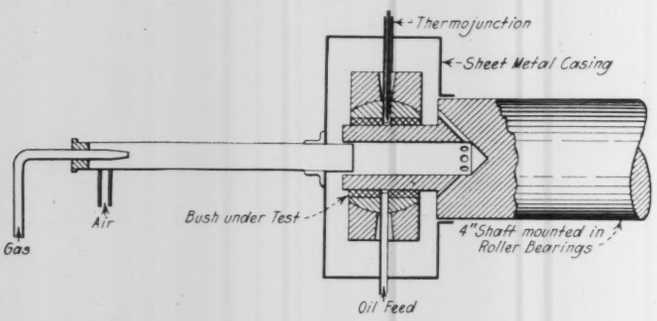

FIG. 4 TEST JOURNAL WITH HEATING ARRANGEMENTS

a low seizing temperature simply because it is a thin oil unsuitable for the load at which the test is made, and not because it is an inferior oil of its class. The seizing temperature of any particular oil depends upon the load, increase in the load causing a fall in the seizing temperature.

The oils sent for test consisted of an oil labeled "L.N." and stated to be produced by the company's method of coal distillation, and an oil labeled "F.B.C." believed to be a straight mineral oil. The densities were:

Oil "L.N." (No.—D.H.R.), 0.981 at 18 deg. cent.
Oil "F.B.C." (No.—D.F.Z.), 0.901 at 17 deg. cent.

It was intended to make running tests at loads of 800, 1000, and 1200 lb. per sq. in., but on starting with oil "F.B.C." it was found that seizures were very sudden at 800 lb. per sq. in., so that there was danger of damaging journal and bush before completing the tests. Tests were therefore made at 800, 600, and 400 lb. per sq. in. Tests were made on oil "L.N." at the same loads, and since even at 800 lb. per sq. in. the seizure was not sudden, a test was satisfactorily completed at 1000 lb. per sq. in. An attempt to run at 1200 lb. per sq. in., however, led to a very sudden and

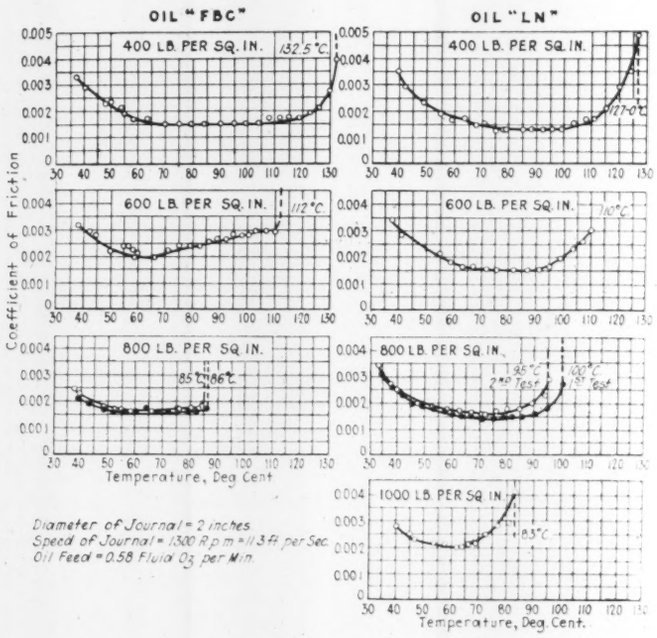

FIG. 5 TESTS ON OILS "F.B.C" AND "L.N" ON JOURNAL-FRICTION TESTING MACHINE

violent seizure of the bearing which did a certain amount of damage to the bush.

The conditions of the tests were as follows:

TESTS OF OIL "F.B.C." (NO.—D.F.Z.)

	Before test	After test
Diameter of bush, in.	2.0107	2.0108 × 2.0115
Diameter of journal, in.	2.0022	2.0022
Difference, in.	0.0085	0.0086 to 0.0093
Maximum wear in vertical diameter, in.		0.0008

TESTS OF OIL "L.N." (NO.—D.H.R.)

	Before test	After test
Diameter of bush, in.	2.0108 × 2.0115	2.0108 × 2.0120
Diameter of journal, in.	2.0022	2.0022
Difference, in.	0.0086 to 0.0093	0.0086 to 0.0098
Maximum wear in vertical diameter, in.		0.0005
Length of bush, in.	2.25	
Projected area of bearing, sq. in.	4.50	
Speed, 1300 r.p.m. = 11.3 ft. per sec.		
Oil feed, 0.58 fluid oz. per min.		

TABLE OF RESULTS

Load lb. per sq. in.	Oil "F.B.C." Minimum friction	Oil "F.B.C." Temp. of min. friction, deg. cent.	Oil "L.N." Minimum friction	Oil "L.N." Temp. of min. friction, deg. cent.
400	0.0015	75 to 100	0.0013	80 to 95
600	0.0020	60 to 70	0.0015	75 to 90
800	0.0016	55 to 60	0.0016	65 to 80
1000	....	.....	0.0020	60 to 65

TEMPERATURE OF SEIZURE

Load, lb. per sq. in.	Oil "F.B.C." deg. cent.	Oil "L.N." deg. cent.
400	132	127
600	112	110
800	85	95[1]
1000	...	83

[1] The first test on oil "L.N." at 800 lb. per sq. in. load which gave a seizing temperature of 100 deg. cent. has been disregarded because the seizing temperature was no doubt partly due to the previous oil left in the pores of the metal.

The curves of coefficient of friction plotted to temperature are given in Fig. 5.

CONCLUSIONS

The density determinations show that "F.B.C." was a lighter oil than "L.N.," and this may account for its failure to run satisfactorily at loads exceeding 800 lb. per sq. in. At the lower loads the seizing temperature of "L.N." is a little lower than that of "F.B.C." but for high loads "L.N." appears to be more satisfactory. The coefficient friction of "L.N." appears to be less than that of "F.B.C." at low loads and the same at higher loads.

Effect of Temperature on the Properties of Metals

Progress Report of Joint Research Committee Organized by The American Society of Mechanical Engineers and the American Society for Testing Materials[1]

THE Joint Research Committee on Effect of Temperature on the Properties of Metals was permanently organized by the two sponsor societies, The American Society of Mechanical Engineers and the American Society for Testing Materials, following a symposium on this subject held at a joint meeting of the two societies in Cleveland in May, 1924. The sponsors proposed that the functions of the committee be as follows:

1 Accumulation of existing unpublished data covering satisfactory and unsatisfactory service of various metals under extreme temperatures in different fields of engineering.

2 The making of studies leading to standardization of the procedure for testing materials at high and low temperatures. These should preferably include studies of new comparative tests of metals by the particular methods now in use in various laboratories, and, likewise, a critical examination of data already published.

3 Outlining and fostering new research work in this field. The first and most important materials to be investigated are considered to be carbon and alloy steels, so-called "heat-resisting" alloys consisting of various combinations of nickel, chromium, iron, tungsten, molybdenum, etc., and trimming materials (chiefly alloys of nickel and copper) for valves and equipment intended for high-temperature service in power stations, oil refineries, etc.

Pursuing this program the Committee set up a schedule as follows:

1 To list laboratories that are in position to perform tests at elevated temperatures and to complete arrangements with them for a preliminary set of tension tests.

2 To formulate a specification, standardizing the methods of testing, machines to be used, types of test bars for the various tests, methods of temperature determination, methods of determining elongation or strain, etc.

3 To formulate specifications for metals to be tested, and to confer with the various steel companies with the view of obtaining the necessary amount of materials to carry on a preliminary set of tests.

Sub-committees were appointed within the Joint Research Committee, these sub-committees reporting at a subsequent meeting briefly as follows:

1 Fifty-three laboratories were addressed and their coöperation solicited. Replies were received from thirty-eight laboratories indicating that between twenty and thirty of them had the necessary equipment and were willing to coöperate in this work to the extent of testing a limited number of bars without cost to the committee.

2 Specifications were presented and adopted for short-time and long-time tension tests. Since one of the valuable results to be obtained from the preliminary tests is a determination whether or not it is necessary that all tests, in order to be comparable, should be conducted with a specific type of equipment, it was decided that for this series of tests each laboratory should use its existing equipment, such as testing machine, extensometer, pyrometer, etc.

3 Approximate specifications were formulated for four classes of steel and later augmented by a fifth class, as follows: a low-carbon open-hearth steel, a stainless steel, a chrome-molybdenum open-hearth steel, a heat-resisting alloy such as a nickel-chromium alloy low in iron, and pure nickel.

As these materials were procured, they were properly heat-treated and a supply of test bars of each was sent to four laboratories. These laboratories work independently of one another and are to make individual reports to the committee.

A sub-committee of three members was delegated to analyze and compare the reports from the various laboratories, and from the report of this sub-committee it will be possible to conclude whether or not it is necessary to standardize upon specific types of testing equipment in order to obtain comparable results. The information obtained from these reports will also supply valuable data concerning the tensile properties of these five materials at temperatures between 70 and 1200 deg. fahr.

[1] Presented at the General Meeting of the American Society for Testing Materials, French Lick Springs, Ind., June 22, 1927.

Complete reports have been received on the low-carbon open-hearth steel and on the chromium-molybdenum open-hearth steel, and these reports have been analyzed by the sub-committee.[2]

Future Program. The Committee has tentatively formulated a program of the most important tests to be undertaken, as follows:

1 Tension tests, short and long-time, now in progress
2 Chemical stability
3 Tension tests of non-ferrous metals
4 Physical and thermal constants
5 Other mechanical tests, for example, fatigue, impact, torsion, etc.

The foregoing program is of such an extent that it will be necessary to pay for laboratory services. The five foregoing items were therefore delegated to sub-committees, which have presented reports as to the desirable scope and approximate cost of each item. These reports indicated that approximately $50,000 would be required for one year's work on this program. The method of financing such a program is being developed by the Committee with the advice of the sponsor societies.

Under item No. 4 a Committee member volunteered laboratory facilities for the purpose of determining thermal expansivity of the five materials now in the hands of the Committee. This report is printed below.

Bibliography. For the assistance of the members, a bibliography consisting of several hundred titles was prepared by the librarian of Henry L. Doherty & Co. and circularized to the committee members. The American Society of Mechanical Engineers recommended that this bibliography be published in an attractive form with the anticipation that it would stimulate interest in this research work among those not directly connected with the committee, and interest which may prompt financial support. By augmenting the bibliography with a digest of the most pertinent information on the subject, the publication should prove valuable to the research worker and also to the technical executive who is in search of a comprehensive but less detailed knowledge of the subject. The Main Research Committee of the A.S.M.E. has agreed to finance the printing of such a bibliography.

Service Information. A sub-committee has drafted a form of questionnaire which is to be submitted to manufacturers of heat-resisting materials and to users of metals under high-temperature service conditions for the purpose of summarizing their experiences, both satisfactory and unsatisfactory, in the use of various materials under such service.

Respectfully submitted on behalf of the Joint Committee,

G. W. SAATHOFF,
Chairman.

F. M. VAN DEVENTER,
Secretary.

Results of Tests on Thermal Expansion of Four Classes of Steel[3]

THIS report covers the determination of thermal-expansion data on two specimens each of materials K1, K2, K3, and K4, submitted by the Committee through Mr. H. J. French.

The bars were forwarded from the Bureau of Standards by letter dated March 25, 1927, and received March 29, 1927. Two bars each were stamped K1, K2, K3, one bar stamped K4, and one bar stamped K4A.

Material K5 was not received in time to include the results in this report.

[2] These reports are printed immediately following this Progress Report.

[3] Thermal Expansion of Materials K1, K2, K3, and K4, for Joint Research Committee on the Effect of Temperature on the Properties of Metals. Report presented by N. L. Mochel at French Lick Springs, Ind., June 23, 1927.

METHOD OF MAKING THE TESTS

All eight specimens were prepared for test and tested in the condition as received, that is, without heat treatment of any kind. Specimens were machined to the dimensions and shape shown in Fig. 1.

The tests were conducted at the Westinghouse Research Laboratory by Mr. L. W. Schad, who has furnished the data and calculations embodied in this report.

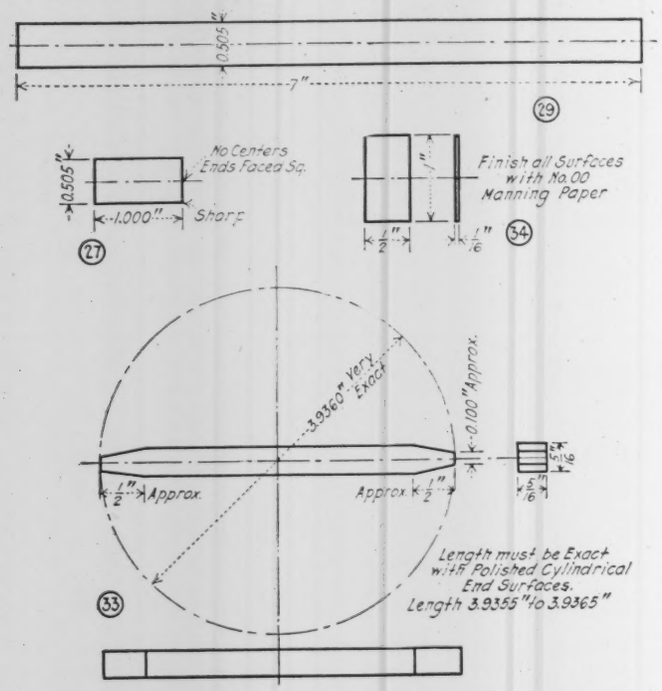

FIG. 1 SHAPES AND DIMENSIONS OF SPECIMENS TESTED

The specimen is supported in an electric tube furnace built to give uniform temperature in the heating chamber. The temperatures are determined with a Leeds & Northrup type "K" potentiometer and copper-advance thermocouples. The thermocouples are carefully calibrated and are correct to within 0.2 deg. cent. up to 350 deg. cent. and 0.5 deg. cent. from 350 to 500 deg. cent. The hot junction of the couple makes contact with the sample. Over each end of the specimen a one-mil tungsten wire is dropped through a small slit in the furnace. To the lower end of each of these wires is attached a 40-gram weight which hangs in oil to prevent swinging. The wires move away from or toward each other, swinging to the amount of expansion or contraction of the sample, and this movement is measured by micrometer microscopes sighted on the wires approximately three inches below the furnace.

TABLE 1 RESULTS OF THERMAL-EXPANSION TESTS

	Temperature, deg. cent.	Length change per unit length		Temperature, deg. cent.	Length change per unit length	
K1	27	310	×10⁻⁶	K1— 22	253	×10⁻⁶
	141	1700		148	1823	
	265	3380		266	3420	
	396	5380		388	5283	
	527	7530		516	7400	
	350	4640		344	4613	
	27	370		210	2640	
				24	283	
K2	27	270	×10⁻⁶	K2— 25	242	×10⁻⁶
	148	1550		165	1700	
	265	2890		282	3040	
	388	4420		386	4340	
	518	6170		515	6090	
	346	3880		329	3640	
	204	2180		24	202	
	24	230				
K3	25	261	×10⁻⁶	K3— 25	274	×10⁻⁶
	148	1640		149	1744	
	268	3260		266	3264	
	389	5020		388	5054	
	522	7170		514	7054	
	349	4480		345	4404	
	215	2540		202	2374	
	24	271		24	264	
K4	25	300	×10⁻⁶	K4— 24	293	×10⁻⁶
	143	1810		147	1813	
	265	3540		264	3493	
	388	5450		388	5393	
	514	7580		514	7563	
	350	4850		349	4803	
	192	2490		197	2523	
	24	210		24	233	

RESULTS OF TESTS

Expansion was determined on all eight specimens over a range of 0 to 500 deg. cent. The observed values are given in Table 1 in the order in which the observations were made, that is, up to 500 deg. cent. and then down to room temperature. In the table, the dash after the figure, as K1—, distinguishes one sample from the other of like material. The dash is also marked on the sample for further reference.

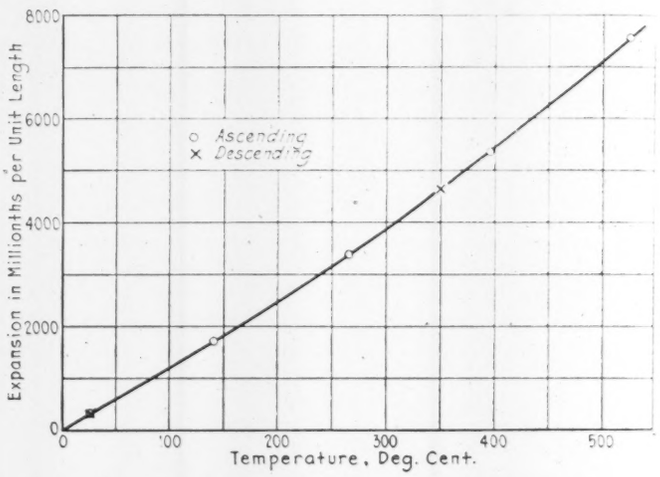

FIG. 2 THERMAL EXPANSION OF K1 (0.17 CARBON STEEL)

$L_t = L_o[1 + (11.19t + 0.0059t^2) \times 10^{-6}]$

Temp. range, 0 deg. cent. to	Avg. expansion coefficient		Temp., deg. cent.	Instantaneous expansion coeff.	
100 deg.	11.78	× 10⁻⁶	0	11.19	× 10⁻⁶
200 deg.	12.38		100	12.38	
300 deg.	12.97		200	13.56	
400 deg.	13.56		300	14.75	
500 deg.	14.16		400	15.93	
			500	17.12	

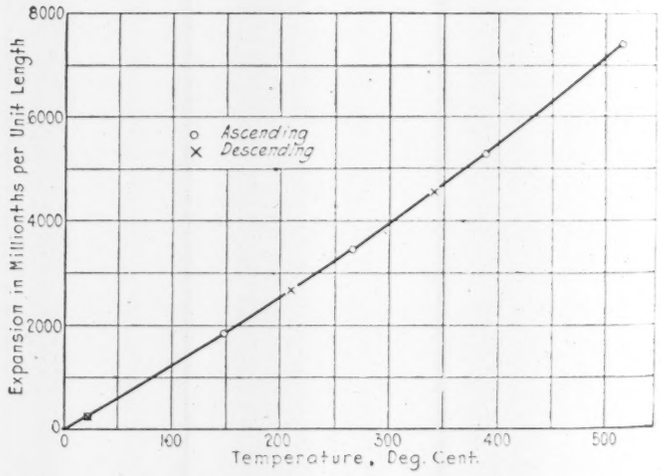

FIG. 3 THERMAL EXPANSION OF K1=(0.17 CARBON STEEL)

$L_t = L_o[1 + (11.39t + 0.00571t^2) \times 10^{-6}]$

Temp. range, 0 deg. cent. to	Avg. expansion coefficient		Temp., deg. cent.	Instantaneous expansion coeff.	
100 deg.	11.96	×10⁻⁶	0	11.39	×10⁻⁶
200 deg.	12.53		100	12.53	
300 deg.	13.10		200	13.67	
400 deg.	13.67		300	14.82	
500 deg.	14.24		400	15.96	
			500	17.10	

The results are also given by plotting length change vs. temperature from the observed values, and these are given in Figs. 2 to 9, inclusive. In addition, an expansion equation obtained by geometrical and mathematical approximation, and a table of average and instantaneous coefficients are given with each figure.

In the expansion equation, $L_t = L_o [1 + (at + bt^2) \times 10^{-6}]$, given with all of the figures, L_t represents the length of a sample at t deg. cent. where t is any temperature between 0 and 500 deg. cent.

L_o represents the length of the same sample at 0 deg. cent.; a and b are constants which are determined by the expansion of the material. From this equation, $(L_t \pm L_o)/L_o$ = expansion per unit length from 0 deg. cent. to t deg. cent. $= (at + bt^2) \times 10^{-6}$, and the average coefficient of expansion is

$$\frac{L_t - L_o}{L_o t} = (a + bt) \times 10^{-6}$$

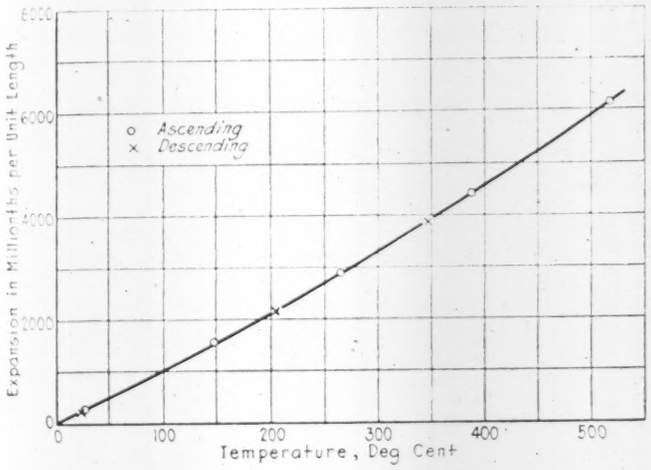

FIG. 4 THERMAL EXPANSION OF K2 (STAINLESS STEEL)

$L_t = L_o[1 + (9.91t + 0.00386T^2) \times 10^{-6}]$

Temp. range, 0 deg. cent. to	Avg. expansion coefficient		Temp., deg. cent.	Instantaneous expansion coeff.	
100 deg.	10.30		0	9.91	
200 deg.	10.68		100	10.68	
300 deg.	11.07	$\times 10^{-6}$	200	11.45	$\times 10^{-6}$
400 deg.	11.45		300	12.23	
500 deg.	11.84		400	13.00	
			500	13.77	

FIG. 5 THERMAL EXPANSION OF K2—(STAINLESS STEEL)

$L_t = L_o[1 + (9.57t + 0.0044t^2) \times 10^{-6}]$

Temp. range, 0 deg. cent. to	Avg. expansion coefficient		Temp., deg. cent.	Instantaneous expansion coeff.	
100 deg.	10.01		0	9.57	
200 deg.	10.45		100	10.45	
300 deg.	10.89	$\times 10^{-6}$	200	11.33	$\times 10^{-6}$
400 deg.	11.33		300	12.21	
500 deg.	11.77		400	13.09	
			500	13.97	

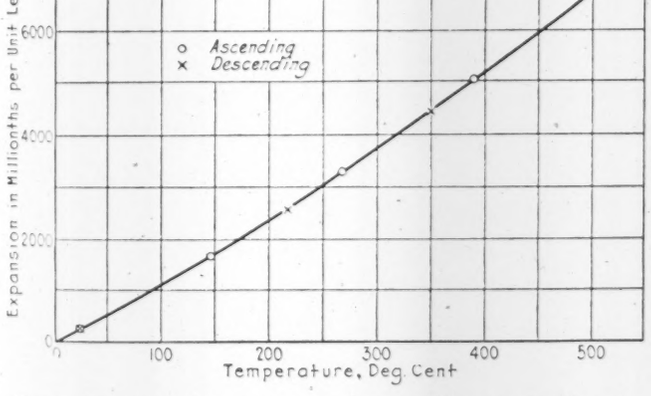

FIG. 6 THERMAL EXPANSION OF K3 (CHROME-MOLYBDENUM STEEL)

$L_t = L_o[1 + (10.45t + 0.0063t^2) \times 10^{-6}]$

Temp. range, 0 deg. cent. to	Avg. expansion coefficient		Temp., deg. cent.	Instantaneous expansion coeff.	
100 deg.	11.08		0	10.45	
200 deg.	11.71		100	11.71	
300 deg.	12.34	$\times 10^{-6}$	200	12.97	$\times 10^{-6}$
400 deg.	12.97		300	14.23	
500 deg.	13.60		400	15.49	
			500	16.75	

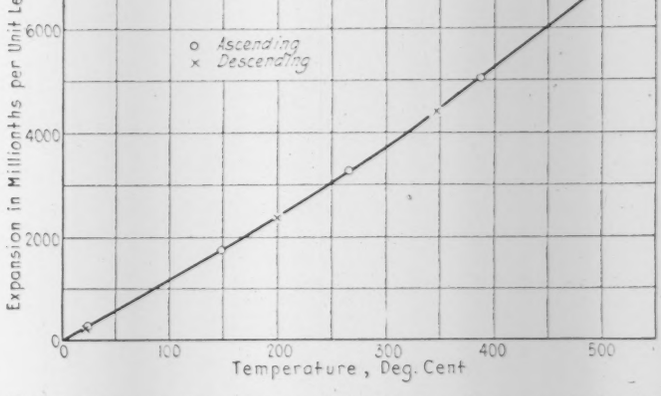

FIG. 7 THERMAL EXPANSION OF K3—(CHROME-MOLYBDENUM STEEL)

$L_t = L_o[1 + (10.80t + 0.0057t^2) \times 10^{-6}]$

Temp. range, 0 deg. cent. to	Avg. expansion coefficient		Temp., deg. cent.	Instantaneous expansion coeff.	
100 deg.	11.37		0	10.80	
200 deg.	11.94		100	11.94	
300 deg.	12.51	$\times 10^{-6}$	200	13.08	$\times 10^{-6}$
400 deg.	13.08		300	14.22	
500 deg.	13.65		400	15.36	
			500	16.50	

The instantaneous coefficient of expansion at any temperature t deg. cent. is derived as follows:

Let the unit expansion or $(L_t - L_o)/L_o = y = (at + bt^2) \times 10^{-6}$; then $dy/dt = (a + 2bt) \times 10^{-6}$ is the slope of the expansion curve at any temperature t, and is therefore the instantaneous coefficient at that temperature.

ACCURACY OF RESULTS

The fine tungsten wires make an excellent target on which to sight with the micrometer microscopes. Readings may be repeated to within two divisions of the micrometer drum which is approximately 1.5 microns (1 micron = 0.0001 cm. or approximately 0.00004 in.). Assuming both microscope settings to be in error by 1.5 microns, the total error is 3 microns and the maximum deviation becomes plus or minus 3 microns.

All of the observations made on the expansion of each sample have been averaged by computing the length-change-vs.-temperature curve, which best fits all the observed points. However, this curve will not exactly fit, and the observed values minus the computed values constitute the deviations. For a specimen that has no irregularities such as internal stresses or transformation regions within the temperature range considered, the maximum deviation is ordinarily about plus or minus 3 microns, which for a sample 10 cm. long is plus or minus 30 millionths per unit length. The average and maximum deviations for each sample show how accurately the length equation fits the observations. Table 2 gives these deviations for each sample.

The length equations for some of the duplicate samples differ in that when the a-term is larger, the b-term is smaller. Superimposing the curves of duplicate samples shows very little difference in expansion between them.

Computing the length changes from the equations in the case of

K3 and K3—, for example, we have 1709×10^{-6} and 1748×10^{-6}, respectively, at 150 deg. cent., and these values differ from each other by a little more than two per cent.

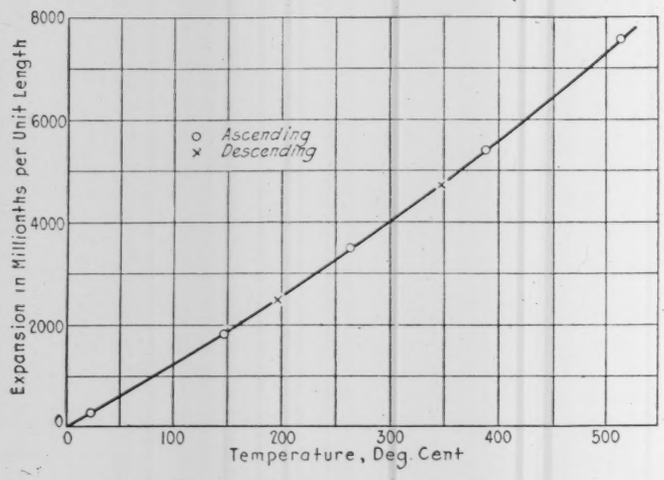

FIG. 8 THERMAL EXPANSION OF K4 (NICHROME)

$L_t = L_o[1 + (11.89t + 0.00555t^2) \times 10^{-6}]$

Temp. range, 0 deg. cent. to	Avg. expansion coefficient		Temp., deg. cent.	Instantaneous expansion coeff.	
100 deg.	12.45		0	11.89	
200 deg.	13.00		100	13.00	
300 deg.	13.56	$\times 10^{-6}$	200	14.11	$\times 10^{-6}$
400 deg.	14.11		300	15.22	
500 deg.	14.66		400	16.33	
			500	17.44	

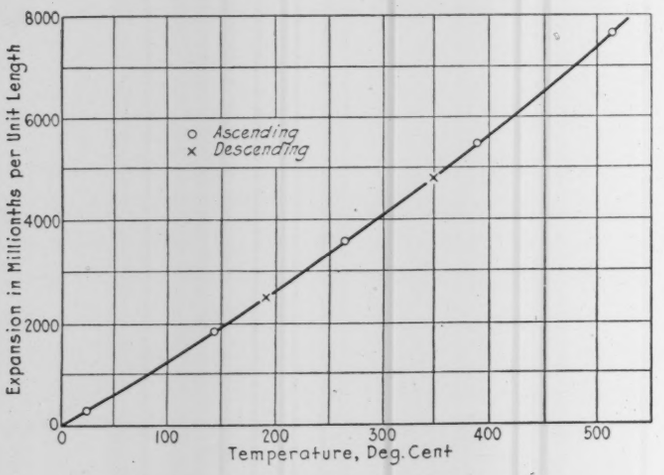

FIG. 9 THERMAL EXPANSION OF K4—(NICHROME)

$L_t = L_o[1 + (11.40t + 0.0065t^2) \times 10^{-6}]$

Temp. range, 0 deg. cent. to	Avg. expansion coefficient		Temp., deg. cent.	Instantaneous expansion coeff.	
100 deg.	12.05		0	11.40	
200 deg.	12.70		100	12.70	
300 deg.	13.36	$\times 10^{-6}$	200	14.00	$\times 10^{-6}$
400 deg.	14.00		300	15.30	
500 deg.	14.65		400	16.60	
			500	17.90	

TABLE 2 DEVIATION OF SAMPLES TESTED

Sample	Average deviation in millionths per unit length	Maximum deviation in millionths per unit length
K1	plus or minus 5	plus 20 at 396 deg. cent.
K1—	plus or minus 6	minus 11 at 266 deg. cent.
K2	plus or minus 2	plus 6 at 147 deg. cent.
K2—	plus or minus 6	plus 12 at 515 deg. cent.
K3	plus or minus 13	minus 47 at 148 deg. cent.
K3—	plus or minus 6	minus 14 at 266 deg. cent.
K4	plus or minus 4	plus 11 at 514 deg. cent.
K4—	plus or minus 16	plus 30 at 264 deg. cent.

TABLE 3 ANALYSES OF SAMPLES TESTED

Mark	C	Mn	P	S	Si	Cr	Mo	Fe	Ni	Cu	Rolled to
K1 (a)	0.17	0.42	0.012	0.035	....	....	....	....	....	....	1 in. rd.
K2	Stainless steel to be analyzed by one of the coöperators										1 in. rd.
K3 (a)	0.39	0.51	0.015	0.029	0.19	0.87	0.21	....	....	....	1½ in. rd.
K4 (a)	0.31	2.79	....	....	0.27	18.8	....	0.80	76.0	0.66	¾ in. rd.
K5	Commercially pure nickel					....	....	....	....	....	cold rolled to 1 in. × 1 in.

(a) Analyzed by manufacturer of the alloy.

Comparative High-Temperature Tension Tests on a Carbon Steel and on a Chromium-Molybdenum Steel[4]

IN THIS report attention was called to the differences frequently encountered in the results of high-temperature tension tests made in different laboratories upon similar metals. It seemed desirable to determine the causes of such differences and whether comparable results could be secured with the procedure and equipment normally employed in different laboratories. Information of this sort might have an added value in that it could furnish the basis for ultimate standardization of high-temperature tension-test methods and correlation with creep test data.

Some twenty-odd laboratories are to coöperate in the investigation, and those of the following firms and institutions have taken part in the first series of tests: Babcock & Wilcox, Bayonne, N. J., Bureau of Standards, Washington, D. C., Chapman Valve Mfg. Co., Indian Orchard, Mass., Crane Co., Chicago, Ill., University of Illinois, Urbana, Ill., University of Michigan, Ann Arbor, Mich., Walworth Mfg. Co., Boston, Mass., Watertown Arsenal, Watertown, Mass.

Results so far received have been obtained on steels K1 and K3, the former being a carbon steel (0.17 carbon), and the latter a chrome-molybdenum steel (0.39 carbon, 0.87 chromium and 0.21 molybdenum). Steel K1 was normalized and steel K3 quenched and tempered prior to test. Each steel was heat-treated at a single laboratory and then distributed to the coöperators for tension tests, which were made under general specifications furnished by the Committee, but with the equipment and procedure ordinarily employed by the respective organizations. Considerable difficulty was encountered in interpreting the reports from some of the coöperators, and it has, therefore, not been possible to make a complete analysis of data pending receipt of more detailed information on certain phases of the work.

The complete report contains results of the tension tests at four different laboratories, showing the effect of temperature on tensile strength, proportional limit, elongation, reduction of area, yield point, and breaking strength. Notable differences in the results were obtained at the different laboratories on the same metals.

Charts given in the complete report show that the actual and percentage deviation from the average tensile strength increases appreciably in the temperature range 800 to 1200 deg. fahr., whereas the actual deviation from the average proportional limit shows no definite tendency to increase with temperature. However, the percentage variation from the average proportional limit tends to increase. It is pointed out that variations from differences in rate of loading in the determination of proportional limits are probably overshadowed by those arising from the differences in sensitivity of extensometers and methods of plotting stress-strain curves, and the report shows in a series of charts the dependence of the proportional limit upon the equipment and procedure employed.

One of the striking features revealed by the stress-strain curves obtained for steel K1 is that the values reported by Laboratory No. 23 for temperatures around 400 deg. fahr. and above are consistently higher than those reported by Laboratory No. 15 at corresponding temperatures. Laboratory No. 23 reported extension to the nearest 0.00005 in. while Laboratory No. 15 reported extensions being measured to the nearest 0.000006 in., yet Laboratory No. 23, using the least sensitive extensometer, reported the lower values for the proportional limits. This would indicate that any advantage gained by the use of more sensitive measuring instruments will only be realized if other important factors entering into the problem of reproducible high-temperature tension tests are also under control.

The conclusion arrived at is that the differences found in the present case clearly indicate that there are details of our present-day test methods and apparatus which are not under sufficient control, and, for example, the desirability of using more sensitive strain-measuring devices for such work as stress-strain curves is clearly indicated.

[4] Abstract of report presented by L. W. Spring, Claire Upthegrove, and H. J. French (*Chairman*) at meeting of the Joint Research Committee on Effect of Temperature on Properties of Metals, French Lick Springs, Ind., June 23, 1927.

Determination of Most Economical Condenser Installation for a Given Power Plant

Comments on a Recently Published Study Based on an Average Heat Transfer Actually Obtained in Surface Condensers of Different Makes Under Normal Operating Conditions

FOR THE power-plant engineer the problem of selecting the most economical condenser for a particular unit is not merely a technical one but essentially of an economic nature, and has to be studied accordingly. With this in mind Messrs. J. A. Powell and H. J. Vetlesen presented a paper at a meeting of the Philadelphia Section of the A.S.M.E. on April 26 last,[1] in which they took as a basis for their study a normal load of 26,000 kw. on a 30,000-kw. turbo-generator, bled at two stages for preheating of the feedwater to 212 deg. fahr., the turbine giving a yearly output of 100,000,000 kw-hr.

Their findings, as a result of the study, were that with sufficient circulating water the most economical condenser installation for a unit is a single-pass condenser for which the ratio of square feet of surface to normal kilowatt output of the turbine it serves is not higher than about 0.77. At 60 deg. fahr. water temperature the installation of a condenser with the said surface-output ratio of 0.77 is justified for water velocities through the tubes above about 5.75 ft. per sec., and at 70 deg. temperature for velocities above about 6.25 ft. per sec. The most economical installation thus found is considerably smaller than that actually installed in modern power plants. The study was based on heat-transfer figures actually obtained under normal operating conditions; these figures, the authors stated, are considerably lower than guarantees now given by most manufacturers, and must therefore be looked upon as being fairly conservative.

An extended discussion followed the presentation of the paper, the greater part of which is given below.

THE selection of the type of condenser has always been not merely a technical but also an economical problem, and has been treated as such by power-plant engineers who issue specifications for the purchase of such apparatus.[2] The solution of this problem depends also a great deal upon the skill in collecting the necessary data which form the basis for such a study. Some of these data can be obtained from actual measurements, but some have to be anticipated from observations made in the past.

The whole matter of selecting the type of condenser is not such a perplexing problem as one may be led to believe after reading the paper. It is nothing more than an exercise in pure logic, supported by mathematical reasoning and based on existing and assumed facts. If the latter have been carefully and conscientiously selected, the problem will be easily solved.

In concluding the paper, the authors make the statement that their study shows "that with sufficient circulating water the most economical condenser installation for a unit is a single-pass condenser for which the ratio of square feet of surface to normal output of turbine it serves in kilowatts is not higher than about 0.77." It would seem that they are advocating a return to the rule of thumb used over twenty years ago, so many square feet per horsepower. But in doing so they have failed to give the data from which this rule of thumb has been derived. In making such a statement as cited above, they may mislead power-plant engineers into believing that the only solution of the condenser problem is to use 0.77 sq. ft. surface per kilowatt and the single-pass type of condenser.

The object of the paper, which as the authors say is to show how a study of selecting the type and size of condenser is to be made, has not been attained, as the data from which the curves of their Figs. 7 to 20 have been prepared are nowhere given in the paper and the reader is left guessing regarding the various assumptions made by the authors. The cost of coal, its thermal content, the boiler efficiency, the length and thickness of the condenser tubes, the heat content of the exhaust steam, the tube maintenance costs, and the assumed cost of condenser per square foot of surface, are all factors influencing the yearly operating cost and as such should have been given prominence in the paper.

The statement "that the study refers to *special conditions*, although these may be regarded as fairly normal," may also tend to indicate that these special conditions have been selected to show a lower operating cost for the single-pass condenser. In selecting some other conditions it would not be difficult to prepare similar curves which would show lower operating costs for the two-pass condenser, especially if the costs of sandblasting and cleaning the tubes are also considered. These operations, as experience has shown,[3] are more frequent with single-pass condensers than with two-pass condensers.

However, it is not the writer's intention to discuss either type, as each has its field of application, but rather to call attention to some points in the paper which require correction.

In the appendix the method of calculation of the vacuum is shown. The arithmetical mean temperature difference has been used in these calculations. This may be the cause of considerable errors when determining the vacuum temperature and the vacuum to be obtained, which in turn would influence the yearly operating costs.

The logarithmic formula

$$t_m = \frac{t_2 - t_1}{\log \frac{t_3 - t_1}{t_3 - t_2}}$$

in which t_m = mean temperature difference
t_3 = temperature corresponding to absolute pressure, deg. fahr.
t_1 = circulating-water inlet temperature, deg. fahr., and
t_2 = circulating-water discharge temperature, deg. fahr.,

should be used for determining the vacuum temperature t_3. In calculating the vacuum obtainable no consideration has apparently been given to the air-vapor-handling capacity of the air pump, which limits the vacuums obtainable, especially at absolute pressures of 1 in. or less. Since the authors are dealing with temperatures of 50 deg. fahr. this is very important and should have been considered.

Fig. 1 of the paper shows the water rate of the turbine at different absolute pressures. The curve shown does not represent up-to-date figures, for it shows only a decrease of about four per cent in steam consumption for one inch increase in vacuum. This difference, according to the statements of the largest turbine manufacturers in the United States, should be from 6 to 7 per cent for a 30,000-kw. turbine operating at 26,000 kw. with two bleeder points, and should extend to 29.5 in. (see Fig. 1 herewith).

Fig. 2 of the paper shows heat transfers for different water velocities. Comparing these with the values given in Table 1 of the paper, it would seem that the authors used the inlet water temperature for determining the heat transfer and the vacuum obtainable. This is incorrect as the mean water temperature should have been used for obtaining these values. It is quite evident that with the same inlet water temperature but with a greater temperature rise a larger heat-transfer coefficient is obtained due to the greater fluidity of the water at higher temperatures, which influences the thermal resistance on the water side.

In Figs. 4 and 5 the vacuums obtainable with different-sized single- and two-pass condensers with 50 deg. fahr. water and different velocities are illustrated. Nothing is said about the water quantities used in determining these vacuums. Comparing the two curves,

[1] Published in MECHANICAL ENGINEERING, May, 1927, pp. 417–421.

[2] From discussion by G. L. Kothny, Executive Engineer, C. H. Wheeler Mfg. Co., Philadelphia, Pa. Mem. A.S.M.E.

[3] See Some Results of Condenser Operation, by E. B. Ricketts, in MECHANICAL ENGINEERING, Mid-November, 1926, p. 1312.

it will be seen that with 5 ft. water velocity the vacuum obtainable in the two-pass condenser is 28.22 in., and in the single-pass condenser, 28.64 in.

The authors have based the calculation of the vacuum on the heat-transfer curves given in their Fig. 2, which are again based on water velocities, the latter being the same for both the single- and the two-pass condensers. It appears unreasonable to expect that the heat transfer for the same velocity should be less in the two-pass than in the single-pass condenser. Hence the only explanation for the reduced vacuum in the two-pass condenser would be that the authors have assumed reduced water quantities when calculating the vacuum. If so, the comparative figures given in the paper are obtained on a basis unfavorable from the start for the two-pass condenser. In making such a comparison practically the same water quantities and water velocities should be used for both types.

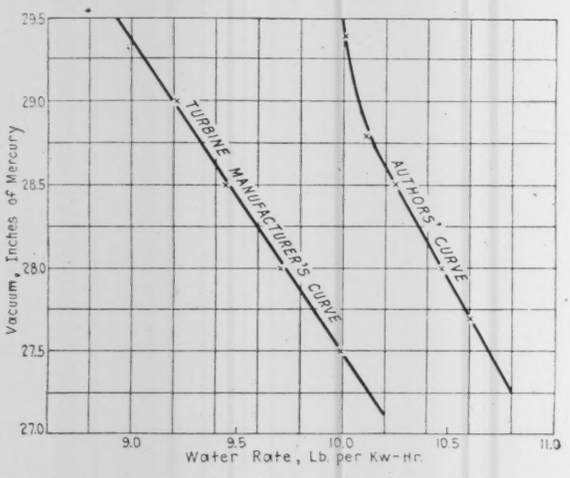

FIG. 1 WATER RATES WITH BLEEDING AT VARIOUS VACUUMS

In this connection it should also be borne in mind that any type of surface condenser performs two operations and therefore should be subdivided into two zones, one in which the steam is condensed, and the other in which the air-vapor mixture is cooled. The latter is called the air cooler. Single-pass condensers are frequently provided with separate air coolers, while the two-pass condensers mostly have the air coolers arranged inside of the condenser shell. It is a very well-known fact that the heat-transfer coefficients for cooling gases are very much lower than those for condensing steam, and that different formulas apply in the calculation of these coefficients.

When comparing single- and two-pass condensers the mistake is frequently made of not adding to the surface of the single-pass condenser the surface of the separate air cooler. The total surface of the two should be compared with that of the two-pass type in order to obtain correct overall heat-transfer figures.

It may be of interest to compare the performance of the condensing zone of the single- and two-pass-type condensers. To obtain the same water velocities in the two-pass condenser as in the single-pass, larger-diameter tubes can be used. The heat-transfer coefficient of the larger-size tube is only slightly less than that of the smaller-size tubes (see W. H. McAdams, T. K. Sherwood, and R. L. Turner on Heat Transmission in Surface Condensers), and this small difference can be counteracted by slightly increasing the water velocities in the larger-size tubes. The thermal resistance of the water film and the tube are only influenced by diameter of the tubes.

The thermal resistance of a tube is

$$r_t = (a/k)\{D_0/[(D_0 + D)/2]\}$$

where a = thickness of tube wall in feet
k = specific thermal conductivity of metal, B.t.u. per hr. per sq. ft. per foot thickness per deg. fahr.
D_0 = outside diam. of tube, inches
D = inside diam. of tube, inches

The thermal resistance on the water side is

$$r_w = \frac{1}{B \times V^{0.8}}, \quad \text{and} \quad B = \frac{D \times 138}{D_0 \times D^{0.2}}\left(1 + \frac{50}{r}\right)(Jf)^{0.8}$$

in which
v = water velocity in feet per sec.
r = ratio of length to inside diameter of tube (inches)
Jf = fluidity corresponding to average water temperature.

Comparing $^7/_8$-in. and $1^1/_4$-in. O.D. Admiralty metal tubes both No. 17 B.W.G. thick, we find from the foregoing formulas,

Thermal resistance of $^7/_8$-in. tube $r_t = 0.0000685$
Thermal resistance of $1^1/_4$-in. tube $r_t = 0.0000673$
Thermal resistance on the water side

$$\text{for } ^7/_8\text{-in. tube } r_w = \frac{0.00648}{V^{0.8}}; \quad \text{for } 1^1/_4\text{-in. tube } r_w = \frac{0.00693}{V^{0.8}}$$

Assuming the individual thermal resistance of any scale r_s plus the individual thermal resistance on the vapor side r_2 as 0.0005, we find the overall coefficient of heat transfer k from steam to water, expressed as B.t.u. per hour per sq. ft. of condensing surface per deg. fahr. mean difference between temperatures of steam and water, as follows:

For $^7/_8$-in. O.D. tube 21 ft. long, 5 ft. per sec. water velocity, and 50 deg. fahr. mean water temperature, $k = 420$ B.t.u.

For $1^1/_4$-in. O.D. tube, 18 ft. long, 5.44 ft. per sec. water velocity, and 50 deg. fahr. mean water temperature, $k = 422$ B.t.u. Practically the same heat transfer will be obtained with both sizes.

Making an allowance of 16.2 per cent in heat transfer for dirty tubes (as the authors have apparently done), assuming that the average heat transfer obtained between cleaning periods is only 352 B.t.u., and also subdividing the condensers into ten sections of equal surface to which the steam will have easy access (which is a matter of proper design), the amount of steam condensed in each section will vary only with the mean temperature difference.

Fig. 2 of the present discussion illustrates the steam flow, temperature rise, and mean temperature difference in both condensers.

It will be noted that in section A of both condensers the temperature difference is 37.71 deg. fahr., while in section K this difference is only 24.19 deg. fahr., In section A, 28,670 lb. of steam are condensed, while section K can handle only 18,570 lb.

The steam distribution in the single-pass condenser is very uneven, while in the two-pass condenser the sections A and K, B and I, etc., lie opposite each other, giving a practically even distribution of steam (46,500 lb.) for each of the five vertical sections.

The advantage of this cannot be underestimated when considering the removal of the air-vapor mixtures and the scaling of the tubes. In the single-pass condenser the temperature rise in the tube is practically twice that in the tube of the two-pass condenser. It is therefore not astonishing that unbiased operators admit that single-pass condensers require considerably more cleaning.

Mr. Ricketts in his paper, Some Results of Condenser Operation,[3] gives the following information regarding the yearly washing and sandblasting requirements of different types of condensers installed in the same station and operated about the same number of hours per annum:

Single-pass condenser B,	sandblasted	3 times
	washed	15 times
Single-pass condenser C,	sandblasted	3 times
	washed	13 times
Two-pass condenser D,	sandblasted	Once
	washed	Once

The single-pass condenser shown in Fig. 2 has 4220 tubes, while the two-pass condenser shown in the same figure has only 3400. By applying the ratio given above for cleaning and also the ratio of the number of tubes, the cost of cleaning per year can be easily estimated for both types of condensers. These costs represent quite a considerable item for the single-pass condenser, which the authors of the paper have not taken into consideration when preparing their curves.

Considering now the additional power required for circulating the water at the velocity of 5.44 ft. per sec. through the two-pass condenser with $1^1/_4$-in. O.D. tubes over that required to circulate the water flowing at the rate of 5 ft. per sec. through the $^7/_8$-in. tubes in the single-pass condenser, we find that there is a difference of only 14.4 b.hp.

With 100,000,000 kw-hr. yearly output the additional operating cost of this power would amount only to about $170 per year.

This sum is only a fraction of the amount given by the authors in their Figs. 6 and 7, and will be more than counterbalanced by the greater cost for cleaning the single-pass-type condenser.

In conclusion, the writer would like to emphasize the fact that the authors could have made their paper more valuable had they given complete data upon which their comparisons, statements, and curves are based, and if they had selected normal and not special conditions for this study. An occasional departure from standard practice is sometimes justifiable, in fact is necessary for the realization of progress, but is hardly advisable when attempting to show how such a study is made.

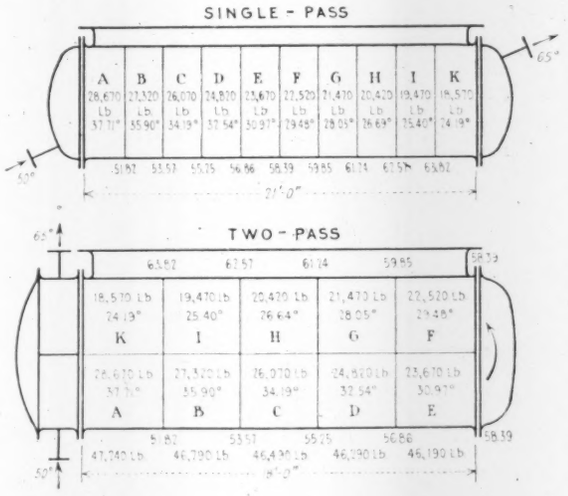

FIG. 2 STEAM FLOW, TEMPERATURE RISE, AND MEAN TEMPERATURE DIFFERENCE IN SINGLE-PASS AND TWO-PASS CONDENSERS

Operating Conditions	
Steam condensed per hour, lb.	233,000
Absolute pressure, in. Hg	1.357
Steam temperature, deg. fahr.	88.6
Surface, sq. ft.	20,000
Inlet water, gal. per min.	29,200
Heat transfer B.t.u.	352
B.t.u. per lb.	840
Single-Pass Condenser	
Number of tubes	4220
Size of tubes, $^7/_8$ in. O.D. No. 17 B.W.G., 21 ft. long	...
Water velocity, ft. per sec.	5
Friction head plus 10 ft., ft.	14.45
Power required, b.hp.	135.4
Two-Pass Condenser	
Number of tubes	3400
Size of tubes, $1^1/_4$ in. O.D. No. 17 B.W.G., 18 ft. long	...
Water velocity, ft. per sec.	5.44
Friction head plus 10 ft., ft.	16.2
Power required, b.hp.	149.8

A COMPARISON is made of single- and two-pass designs employing $^7/_8$-in.-diameter tubes in each case.[4] We are prone to overlook the fact that until recent years the majority of power-plant operators did not look with favor on the use of tubes less than 1 in. in diameter. Recently many condensers have been installed using $^3/_4$-in. and $^7/_8$-in.-diameter tubes; therefore a change in thought has taken place, dictated by the recognition of the necessity of frequent tube cleaning, which is readily permitted by the isolation of one-half of the condenser by adopting the divided-water-box construction. This fact is mentioned because the application of single-pass condensers would be very limited, indeed, if tubes smaller than 1 in. in diameter were impracticable.

We should not lose sight of the fact that the ratio of 1:1, that is, one square foot of condensing surface per kilowatt, is rarely exceeded for central-station work in England. Installations such as Boston Elevated employ 1:1, the Duquesne Light Company uses 1:1.24, and a recent unit purchased by the Commonwealth Edison Company provides 0.86 sq. ft. per kilowatt.

The authors assume an external pumping head of 10 ft. in each case. It is obvious that if we assume the same intake and discharge tunnel areas, the external head for the single-pass unit would be greater than that for the two-pass, resulting in a greater pumping charge for the single-pass, not indicated in the paper. On the other hand, to maintain the same external head, the costs of tunnel, piping, and valves would be greater, particularly for installations where divided water boxes are used, and where there is any appreciable length and size of tunnel. While the cost of tunnel and piping may be of no particular moment in one plant, it may involve a considerable expenditure in another.

The authors apply the same basic price per square foot for both condensers; however, in practice the cost per square foot of the single-pass is greater than that of the corresponding two-pass, assuming the designs to be comparable, due to increased sizes of water boxes and circulating pumps to accommodate the greater water quantity.

Studies made by the company with which the writer is connected to determine the economical diameter and length of tube, also the most economical water velocity, indicate that the lowest yearly operating cost will result from the use of:

1 Tubes of least diameter
2 Tubes of greatest length
3 A most economical velocity for various tube diameters and lengths.

While these studies may show a certain water velocity to be the most economical, nevertheless a thorough investigation should be conducted as to the effect of the velocity on the life of the tube, and the writer understands that the Condenser Tube Research Committee appointed by The American Society of Mechanical Engineers is to cover this phase of the subject.

Considerable stress and attention has been given to the distribution of steam to the tubes in order to improve the efficiency of the condensing plant. On the other hand, but little attention has been given to the hydraulic system, which not only involves water-box design, but also piping to and from the condenser. It is well known that many tubes are inactive due to lack of water supply and back flow of water through the tubes, and these remarks apply equally well to single- or multiple-pass condensers.

In conclusion, the writer cannot help but comment on a remark made by Mr. Bancel[5] in which he compares the square-foot–kilowatt ratio of the 60,000-kw. turbine unit of the Interborough Rapid Transit Company with the 60,000-kw. unit recently installed by the Buffalo General Electric Company. Obviously he leaves the impression that this difference is entirely due to the type of condenser. He neglects to mention the very important fact that the load factor at Buffalo General Electric does not exceed 17 per cent, or, using Mr. Bancel's figure, 11 per cent. Further, the unit is somewhat of a standby for hydroelectric power, and the yearly average water temperature is considerably lower than that encountered in the vicinity of the Interborough plant.

IN TABLE 1 of the paper a constant transfer of 352 B.t.u. at 5 ft. per sec. tube velocity is assumed for all conditions, regardless of the fact that better heat transfer is obtained with higher mean circulating-water temperatures.[6] In the first column water is indicated to rise from 50 to 65 deg., mean 57.5 deg., and in the last column from 50 to $57^1/_2$ deg., or $53^3/_4$ deg. mean water temperature.

The assumed cost of $3 per sq. ft. is high for all sizes, favoring impractical reduction of surface, which is further favored by the assumption of cost as a simple function of surface. If the compared units were condensing an equal weight per square foot per hour the assumption of cost in direct ratio to surface would be approximate, but Table 1 is figured upon an equal total of 233,000 lb. of steam per hour in all five cases. At a vacuum of 1 in. abs., steam occupies a volume of 654 cu. ft. per lb. weight; and therefore the exhaust connection from turbine to condenser and the condenser shell and passages to the tube surface must be designed for a steam flow of 150,000,000 cu. ft. per hour at 1 in. abs. for all surfaces figured, from 20,000 to 40,000 sq. ft. The total cost of the 20,000-sq. ft. condenser should therefore be about two-thirds, rather than one-half, the cost of the 40,000-sq. ft. condenser, and the fixed charges of the 20,000-sq. ft. condenser increased approximately one-third.

The five cases in Table 1 are figured upon a practically even ratio of gallons per minute equal to 146 per cent of surface, further

[4] From discussion by D. W. R. Morgan, Mgr., Condenser and Internal-Combustion Engineering, Condenser Dept., Westinghouse Electric & Manufacturing Co., Philadelphia, Pa. Assoc-Mem. A.S.M.E.

[5] Operating Performance of Some Modern Surface Condensers, by Paul Bancel, MECHANICAL ENGINEERING, March, 1927, pp. 219–226.

[6] From discussion by John F. Grace, Designing Engineer, Henry R. Worthington, Harrison, N. J. Mem. A.S.M.E.

penalizing a liberal condenser. Had the authors also figured surfaces of from 20,000 to 40,000 sq. ft. with a constant quantity of water such as 30,000 or 40,000 gal. per min., or g.p.m. × surface equal to a constant, a greater surface would have been shown to be more economical.

It must be remembered that condensers are used only in the interest of lowered steam-turbine water rate or overall plant efficiency, and that sustained vacuum over the year is the measure of this. The value of the condensing plant, including everything from water intake through condensers and back to water discharge, can be determined by a calculation of dollars-and-cents costs and economies. Such a calculation must be divided into two parts. The first is the value to the plant of each additional tenth of an inch lowered absolute back pressure, and this depends on the turbine and on the total cost of plant per kilowatt of capacity. The turbine design will determine the coal saved per year for a tenth of an inch reduced back pressure, and the plant cost will determine a fixed-charge saving due to additional capacity of station resulting from the same lowered back pressure. The sum, when all things are considered, gives an annual credit in dollars per year for each additional tenth of an inch reduction of back pressure that might be produced by a condensing outfit.

The second part of the calculation of value is concerned with the cost of producing and maintaining the reduced back pressure, and this is the sum of the fixed charges on the whole condensing system and its yearly operating expense, including a charge for power absorbed by it. This debit item is also a yearly sum in dollars.

Subtracting the cost of the vacuum from its gross value leaves a net value in dollars per year, and each additional tenth of an inch lower back pressure has its own figure. This is the correct way to judge condensers, and the economic principles involved are exactly the same as are applied to boilers and to the plant as a whole. With these facts so clear, it is very strange to find most condenser discussions dealing with only one phase of the problem, surface or heat-transfer rate, for example, and wholly ignoring the overall situation of true values.

According to our experience, high vacuums nearly always pay in spite of the additional investment required by the condensing equipment, and when they do not, it is because the turbine design is such as to be unable to utilize the lowered back pressure, or perhaps because so cheap a fuel is used that saving it is not worth while.

The cost of the circulating-water tunnel system, racks, screens, sluices, screen house, etc., sometimes several dollars per gallon per minute circulated, and the high fixed charges resulting from reduction of surface and increase in water circulated, as well as the cost of power for large traveling screens and cost of repairs, and higher overhead resulting from requirement of larger piping, valves, expansion joints, suction wells, floor joints, etc., have all been omitted —to the great benefit of the smaller condensers requiring larger quantities of water. Increased fixed charges resulting from circulation of greater water volume have been ignored.

The water-rate curves, Figs. 1 and 18 of this paper, start to break at an unusually poor vacuum, further penalizing the gains obtainable by installation of liberal surface.

The authors apparently advocate the general adoption of so-called "modern"-type single-pass condensers with high tube velocity and high heat transfer. This type has its proper limited field, usually in application to emergency units of low load factor. Condensers of this type with $^5/_8$-in. tubes designed by Worthington and built and installed in Destroyers 39 and 46 by the Fore River S. B. Co. in 1911 showed heat transfers of 850 B.t.u. on official trials; but in power stations where size and weight are not limited by the compulsion of transporting the apparatus, higher load factors justify additional investment in liberal surface.

The papers presented at the 1926 Annual Meeting of the A.S.M.E. by Messrs. E. B. Ricketts and Paul Bancel showed much more frequent cleaning of the single-pass condensers of reduced surface, and point to a tube-cleaning cost exceeding that assumed by Messrs. Powell and Vetlesen.

The authors assume tube-maintenance cost in direct proportion to surface. Tube replacements in the smaller condensers of the single-pass type may be greater than in the larger two-pass condensers due to tube-outlet temperature conditions, and especially if higher tube velocities are employed in the smaller condensers. The quality of the water circulated is an important factor. The tube velocity should not be chosen without regard to the behavior of the water at high velocity. Velocities as high as 7 to 8 ft. per sec. are relatively safe when clean, nearly air-free water is circulated. The addition of salt reduces the surface tension of water, rendering easy the formation of bubbles and foam. Especially in harbor waters, which are more selectively corrosive than clean sea water of higher salt content, foam cores form at the higher velocities within the water boxes adjacent the tube inlets. Such foam cores are severely corrosive. Tube velocities, tube inlets, and water-box design should be chosen with regard to water conditions. Foam attacks are more deadly to tubes than even the action of bubbles formed in small vortices which result in tube destruction by oxygen attack and water hammer. Foam attack is discussed on pp. 109, 117, 118, and 119 of The Causes and Prevention of Corrosion, by Allen A. Pollitt (Van Nostrand), and the vortex problem is ably presented by Sir Charles Parsons on p. 433 of *Engineering*, April 8, 1927.

The correct proportion of condenser surface to rating of turbine is governed by location, water temperature and quality, and load factor and economy of turbo-generator, and therefore each station has its own factor of most economical proportion of surface to kilowatts. Local conditions determine the correct diameter and length of tube for sustained service and economy, and consequently whether a condenser shall better be of the one- or two-pass type. In an average case of a large base-load unit of high pressure, bleeder type, a surface-to-kilowatts factor close to unity and a two-pass circulation are most often indicated, due to preference for tubes of 1 in. diameter for the waters usually circulated. In a paper on Steam Condenser Practice and Performance,[7] F. J. Chatel cites a surface factor of 0.95 to 1.05.

We seek, principally, not high theoretical heat-transfer coefficients but sustained high vacuum, usually not consistent with extremely high B.t.u. performance; and therefore recommend more liberal condenser surface and the circulation of less water than chosen by the authors so that cost and fixed charges of the tunnels and circulating system may be reduced and good dividends returned from investment in liberal surface in the forms of continuity of service and improved station economy.

IN THE brief oral discussion which followed, P. A. Bancel[8] said that the question of two-pass versus one-pass condensers given so much prominence in the paper and in Mr. Kothny's discussion really meant very little in condenser design. The main question to be decided was the length of flow of the water through the condenser. If a path of 30 ft. was considered desirable, it was merely a question of construction as to whether it should consist of one tube 30 ft. long or two tubes each 15 ft. long. The data given by the authors hardly justified the elimination of two-pass condensers in favor of the single-pass. In many installations, present practice, he thought, would still point to two-pass condensers.

N. E. Funk[9] said that the conclusions drawn by the authors from the data they had so carefully assembled were too rigid; in fact, the paper might be improved by omitting the conclusions. The fact was often disregarded that overall plant economy might not result from operating any particular unit in the plant at the lowest cost point on its curve. This meant that the effect of the performance of any particular unit on the overall economy of the plant must be considered as well as the economy of the unit itself. Tunnel and screen costs were too large a part of the investment in the condenser end of the plant to be neglected.

AUTHORS' CLOSURE[10]

THE data from which the curves Figs. 4 to 20 were prepared were given when the paper was presented at the meeting of the Philadelphia Section of the A.S.M.E. on April 26 last. In order to shorten the paper these data were omitted in the May issue of MECHANICAL ENGINEERING but were published in the June issue and

[7] MECHANICAL ENGINEERING, March, 1927, p. 227.

[8] Ingersoll-Rand Co., New York, N. Y. Jun. A.S.M.E.

[9] Operating Engineer, Philadelphia Electric Co., Philadelphia, Pa. Mem. A.S.M.E.

[10] Closure to discussion by the authors of the paper, Messrs. J. A. Powell and H. J. Vetlesen.

give information regarding all assumptions made for the calculations, and the technical figures as well as the cost figures used as basis were stated.

The study refers to specific conditions, as a concrete case had to be used for showing the method of comparison. The term "special conditions" as used in the paper evidently may give the impression of exceptional conditions as questioned by Mr. Kothny, which is not the case. The case chosen was as near normal conditions as can be obtained, and the effect of variables in the result was studied in order to obtain conclusions which may be regarded as generally valid.

For the calculation of the vacuum the arithmetical mean temperature difference has been used and not the logarithmic, as the former appears to be used by most manufacturers in their calculations, and the difference is not material when the same method is used for all comparisons.

The water rate of the turbine at different absolute pressures was plotted in Fig. 1 from figures received from the manufacturers of the 30,000-kw. turbine considered. The slope of the line given by the different manufacturers was not materially different. As to extension of the straight water-rate curve up to $^1/_2$ in. mercury absolute pressure, this is only possible with a turbine having a very large exhaust end which may fully utilize the high vacuums. This was pointed out in the paper, and the influence on the result when the higher vacuums may be fully utilized was given in separate curves.

If mean temperatures are used instead of inlet temperatures for determining the heat transfer and the surface of the condenser, this will favor smaller condensers and thus affirm the conclusion drawn

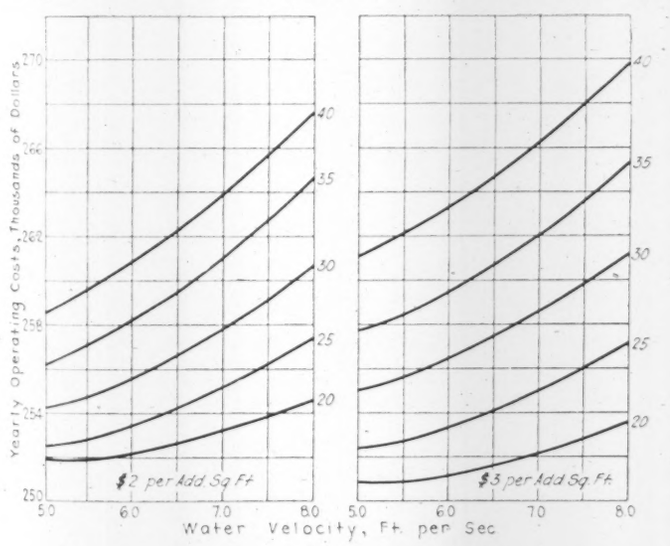

FIG. 3 YEARLY OPERATING COSTS—SINGLE-PASS CONDENSER
(Costs based on 26,000 kw. load, 233,000 lb. steam condensed per hour, 100,000,000 kw-hr. yearly output, 50 deg. fahr. inlet water temperature, and $^7/_8$-in. O.D. condenser tubes.)

that the installation of smaller condenser surfaces than now customary would be more economical.

The heat transfer is the basis for the calculation of the condenser. For given tube dimensions the heat transfer depends upon the velocity through the tube, and as the relation between velocity and heat transfer is easily given in curves it seems logical to base the study on water velocities and let the quantities alter accordingly. With properly designed single-pass condensers it is possible to obtain heat transfer equal to that of a two-pass condenser. This is assuming correctly built condensers, which may be done as the authors do not compare makes of condensers. The use of external air coolers, hot-well heating of the condensate, steam distribution, etc. are for this reason not drawn into the picture. Allowance for these devices will have to be made when comparing different makes, which was not the object of the paper.

Mr. Kothny finds that when reducing the length of the tubes in a two-pass condenser and increasing the tube diameter and comparing same with a single-pass condenser with longer and smaller-diameter tubes, the same performance for both condensers may be obtained with a comparatively small increase in velocity and yearly operating cost for the two-pass condenser which will be more than counterbalanced by the smaller costs for cleaning the two-pass condensers.

Generally, the length of the tubes cannot be changed at will but is more or less dependent upon the space limitations, dimensions of the turbine, etc. In most power plants, therefore, the length of the tubes will be specified and cannot be altered to a great extent. The cleaning necessary will depend upon the local water conditions, and must therefore be considered separately for each case. If the water has a tendency to form scale on the tubes, a more frequent cleaning will be necessary with a single-pass than with a two-pass condenser. If, however, the water contains mud and slime, the reverse will be the case, and a more frequent cleaning will be necessary for a two-pass condenser than for a single-pass condenser.

The costs of water tunnels and piping system should, as pointed out by Messrs. D. W. R. Morgan and John F. Grace, be borne in mind when a condenser study for a given plant is made. These costs will, however, depend entirely upon local conditions, and it will be found that in many cases the local conditions will favor the arrangement with a single-pass condenser and bring the pipe and tunnel costs for same down to or below those of a two-pass condenser

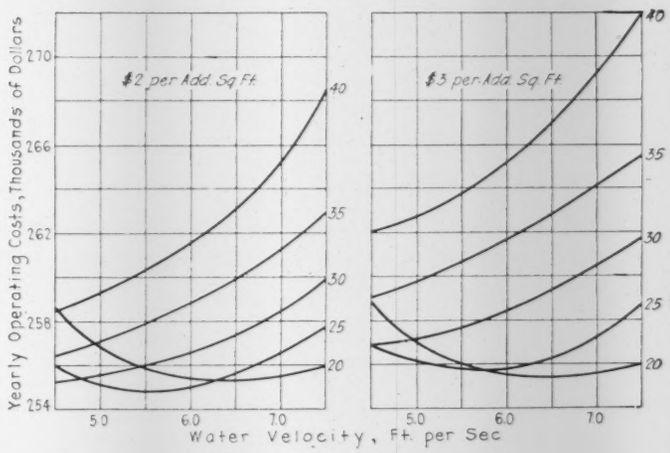

FIG. 4 YEARLY OPERATING COSTS—TWO-PASS CONDENSER
(Curves based on same data as those given in caption of Fig. 3.)

even if the water quantity for the latter is somewhat lower. The authors, therefore, found it not correct in general to penalize the single-pass condenser with greater tunnel costs, but regard it as a consideration which depends upon the local conditions.

The cost of $3 per sq. ft. assumed is for *additional* surface above 20,000 sq. ft. and cannot be used proportionately for smaller surfaces. It was assumed, however, that for additional surfaces above 20,000 sq. ft. an additional price proportionate to the additional surface could be used, and quotations received show this to be fairly correct within limits. This cost of $3 per sq. ft. may be somewhat high, and the curves Figs. 3 and 4 given herewith and which were also exhibited when the paper was read in Philadelphia, were therefore worked out showing that, if the cost assumed per sq. foot of additional surface is reduced to $2, this will have little effect on the result.

Mr. Grace indicates that the correct way to judge condensers is to find the gross value of each additional tenth of an inch lower back pressure and compare it with the additional cost for obtaining it and thus find the net value. This is actually what has been done in this study with the velocity as common basis. The heat transfer and vacuum obtained were figured, the effect of the vacuum on the water rate and yearly operating cost calculated, and the cost for obtaining this vacuum balanced against the value of the vacuum.

It has been the authors' aim not to advocate extremely high heat transfer but to point out that with conservative heat-transfer figures actually obtained and below those now guaranteed by most manufacturers, well-designed condensers with smaller surfaces than generally used today will give the most economical condenser installations.

The Management of Railway Shops and Terminals

The Work Which Is Done at Railroad Terminal Shops and the Organization Which Does the Work

By WILLIAM R. HARRISON,[1] ARGENTINE, KAN.

IN THIS paper the author endeavors to cover the subject in three different phases, as follows: (1) Objectives, (2) organization, and (3) personnel.

The practices that are enumerated, and the figures that are quoted, have been taken from the records of the Kansas City Division of The Atchison, Topeka, and Santa Fe Railway Company. They have been used to explain more clearly the management of shops and terminals.

The successful operation of a railroad, or of any industry for that matter, requires the very closest coöperation between the various departments. On a railroad, if there is any department that the mechanical department should coöperate with, it is the stores department, as it is necessary to have the material in order to get the production and get the power properly turned out in a reasonable length of time. The stores department of the railroad just mentioned is second to none, and if it is given the proper support, there is no delay for material. The mechanical department is, in a good many cases, responsible for the material shortage, due to the fact that it does not give the necessary advance information. It cannot expect the stores department to invest millions of dollars when it is not advised of the needs of the mechanical department.

Objectives

In the management of railway shops and terminals, one might raise the question, "Why a terminal?" It is necessary that definite points be designated as "terminals," at which locomotives, cars, and all equipment incidental to the operation of a railroad shall be given the necessary attention and repairs.

The locomotive has progressed greatly in size and improvements, but terminal facilities today, as quite often is the case, are obsolete and inadequate for handling large modern power. The result is that the handling of the power is slowed down to a great extent, and the cost of handling is increased. These two items are of great importance in the successful and economical operation of a railway terminal. Of course it is practically impossible to have a modern terminal at every point on a railroad, and this being the case, it behooves every one to use the available facilities to the very best advantage and interest of the management.

The Power Plant

The power plant is one of the most vital parts of any terminal. It should be of sufficient size to meet the demands, and should be maintained in a first-class condition at all times and operated as economically as possible. This can be done by maintaining the boilers in first-class condition; the brickwork must be kept free from air leaks, and baffles must be properly maintained. Feedwater heaters are practical and necessary for economical service. The plant as a whole must be free from air and steam leaks to avoid waste of fuel. It is very necessary to maintain the water level in the boilers so as to prevent priming or pulling the water over into engines and compressors, as this is detrimental as well as dangerous.

The Locomotive

As soon as a locomotive arrives on the roundhouse pit track, it should be tested out for pounds and blows. This is very important, as blows can be more accurately detected by a standing test than by a running test. This also eliminates the necessity of having to rely upon what is commonly called a "blanket report" by the engineer. The workman who is assigned to the position of testing should be competent—one who realizes the responsibility of his position. If he is conscientious and puts initiative into his work, he is, unquestionably, one of the most valuable employees, as the work is done strictly according to his reports.

The next move is to get the locomotive watered, sanded, and coaled. This is done on the inbound tracks, as it has been proved by experience that the chances for delays are lessened. It will be realized that every minute of time counts when five men are waiting for the locomotive, and the dispatcher, planning on its getting out on the road on time, arranges his meeting orders on the road accordingly.

After a locomotive is coaled it should be immediately placed on the cinder pit and its fire should be "knocked;" for if a locomotive is allowed to stand on the pit tracks unnecessarily, it is a waste of fuel. All time that a locomotive is on the pit track may truly be called "lost time," because no work can be done on it. In a good many cases a delay of one or two hours on the pit track will mean a setback to a train that has been ordered, due to the fact that the locomotive had been delayed in getting to the roundhouse. The result is that the repairs to it are not completed as promptly as they would have been if there had been no delay. It is the primary duty of the mechanical department to furnish the power as required by the operating department, and in condition to take the train to destination without delay.

The Boiler

The boiler is the heart of the locomotive, and it must be maintained in as nearly perfect condition as possible. The flues must be blown out after each trip, if a free-steaming locomotive as well as fuel economy is expected. The fireboxes must be kept free from leaks, and this means that the boilers must be washed regularly and thoroughly. With flues welded into fireboxes, and with the proper inspection, there should be no trouble due to flues leaking. Fireboxes, properly scaled, where the water conditions justify, will keep the radial stays and the staybolts from leaking. In bad-water districts the fireboxes should be scaled as often as water conditions require.

Arch tubes should be properly applied, beaded on both ends to insure safety. They should be scaled every time the boiler is washed, and thoroughly inspected for defects such as blisters bulges, or warps. Special attention should be given to the condition of the arch flues where they are rolled into the sheets, as well as to the condition of arch-flue beads, which must be first class so that the flues will not pull through the sheet. Serious if not fatal injury to one or more persons might result if arch flues should have defective beads and pull out of the sheet. The arch tubes cannot be given too much attention.

Boiler records are of the utmost importance and should be properly maintained, as these records are very necessary in case of accidents; also a record as to the mileage on flues and the life of the fireboxes, so that an investigation of the records will reflect what is actually being done, and also furnish information as to maintenance costs.

In the line of boiler work a hot-water boiler-washing system is of prime importance, as there is nothing more detrimental to fireboxes than the use of cold water in them. A water-softening plant also is considered of vital importance, and where the lime and soda-ash treatment is used it is necessary to provide tanks of sufficient size to allow water to settle properly; if this is not done, good results will not be forthcoming.

Grates should be maintained free from lost motion, and properly cleaned each time that the fire is knocked.

Air leaks offer the greatest trouble that the terminal force has to contend with. There has been a wonderful improvement in this

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Contributed by the Management Division and presented at the Kansas City Meeting, Kansas City, Mo., April 4 to 6, 1927, of The American Society of Mechanical Engineers.

respect in the last few years, but even so, only a start in this direction has been made. Everything possible must be done to eliminate air leaks. Getting rid of the superheater damper will help, and tests have shown that this can be successfully done. Better designs of steam-pipe casings, which have been accomplished by some designers, have made this detail impervious to leakage. The elimination of the old cinder hopper was a move in the right direction.

If there is a thoroughly competent man needed on the railroad it is the boiler inspector, as he has one of the most responsible jobs of any of the mechanics. He should be a thorough mechanic, with good judgment, and a well-trained eye and ear. It takes a lot of training to get the man to the point where he can be trusted, but, regardless of how much confidence you may have in him, his work should be checked by his supervisor and by general or assistant general boiler inspectors.

RUNNING GEAR

Leaving the boiler and going to the machinery of the locomotive, we are confronted with the necessity of a good, competent inspector, as the major part of what is known as running repairs rests with the inspector. He can prevent a lot of trouble if he is a good one, but if he is a poor one, or indifferent, he will cause no end of worry. It takes much training and experience to make a good inspector. In order to encourage him a supervisor should be careful not to criticize his judgment too often concerning the work which he reports, lest he feel that it is useless to report conditions.

Driving-box wedges should be inspected after each trip to see if they are properly set up. Many times locomotive wheels have been dropped for no reason other than that driving-box wedges were allowed to run improperly set up. This results in taking power out of service when it is badly needed, and in unnecessary added expense. With the driving boxes and wedges come the rods. With the use of solid rods and floating rod bushings a heavy load has been taken from the roundhouse forces, but these should be watched and not run beyond the limit of wear; otherwise broken pins, frames, pistons, and crossheads will be the result. Rods, pistons, crossheads, and valve-gear parts should be cleaned and given a coat of whitewash every time they are removed from the locomotive, and then hammer-tested for cracks, flaws, and defects. Surprising results will be obtained.

CERTIFIED INSPECTION

The certified or monthly inspection should be most rigid. Some railroads have an elaborate plan of inspection to make at this time, but feel that, in a good many cases, it is carried too far. While this is a problem that is up to each individual road or chief mechanical officer to decide, the following are a few of the items that should have attention at the time of these inspections:

Examine tank-truck brasses
Whitewash and test solid-wheel center and axles for defects
Remove and examine boiler checks, and clean boiler-check openings and holes in boiler
Clean out and test main lubricator, and examine lubricator choke to steam end of air pump
Clean out and test flange oilers; ascertain if flange-oiler piping is in good order
Examine and clean chokes
Examine steam and oil pipes at tank header
Examine and clean out cold-water squirts, pipes, and connections
Wash out boiler and tank
Examine tank valves and water valves in leg of tank
Examine tank hose and strainers
Test out steam pipes and nozzle
Examine sand piping and clamps
Remove injector branch pipes, take apart, and thoroughly clean off lime
See that electric-headlight dynamo and wiring are in good condition
Clean out all old packing and repack all eccentric straps
Examine and clean out drain pipes on back of tank
Scale firebox
Examine air-sander nozzle
See that tank boxes are equipped with standard set of tools; oil jacks in tool boxes
Try fountain valve and 3-way cock to reversing gear
Clean out oil holes in valve gear
Empty lantern founts of signal oil and clean founts
Water glass should be removed and inspected for slight or heavy corrosion
Ascertain whether or not all plugs in bottom water-column sleeve and fittings were removed and cleaned out, and passageways to them cleaned out and reamers used on these fittings
Examine engine trucks for lateral
See that engine-truck cellars fit properly up to journals
Examine trailer boxes for lateral
See that trailer cellars fit properly up to journals
Wash feedwater heater
Inspect hydrostatic test valves to feedwater heater
Repack top of engine-truck boxes.

Driving springs should be kept level in order to keep locomotives level, as well as to make them ride easy. Lateral should be kept well within the limit of wear. Flanges should be watched so as not to get to the limit of wear. The engine should be kept up off the boxes and frames so there will be no danger of derailment. The proper oiling of the locomotive parts, such as spring and driving-brake rigging, radial buffers, engine-truck and tank-truck center castings, and hangers and pins to engine and tender trucks, should be watched.

If the work indicated is properly done, a locomotive will do the following:

Handle the required tonnage or the number of cars at the required speed
Consume the minimum amount of coal
Make successful trips on long runs
Have low running repair costs
Perform satisfactory service for the maximum number of hours out of each twenty-four; and at the same time the least possible number of locomotives will be reviewed in service, thus reducing the cost of operation to a minimum.

PASSENGER CARS

Passenger-car equipment must be kept in first-class condition as to repairs and cleanliness, as the public is very critical and is within its rights in expecting such service.

When the passenger trains arrive in the coach yard, the inspector blue-flags the train; the engine is cut off and allowed to proceed to the roundhouse. The air equipment is then tested with a portable air-test rack. The air is set by service application, and then followed by a light reduction and graduated release. The steamheat equipment is also tested at this time and all necessary repairs made. The brake rigging, springs, axles, wheels, flanges, and draft rigging of the cars are then inspected for defects. The journal brasses and packing on all cars are inspected, and the journal is inspected with a packing hook to detect if any babbitt is slipping in the brass, or if the journal is rough. This inspection is very reliable, and, if done properly, hot boxes on passenger cars will eventually be eliminated.

All boxes are repacked every four months, and all brasses removed and inspected. In addition to the daily inspection, wheels, and axles are whitewashed every 90 days in order to discover any cracks or defects. Each car is stenciled to indicate when it is next due for inspection. All wheels removed on account of cut journals, or to have tires turned, are also whitewashed and inspected for defects. During the winter months it is necessary to keep all serviceable passenger cars on the steam line in order to have them ready for service on a moment's notice.

Water coolers are removed from all cars each trip and thoroughly washed. In addition to this, all water coolers are sterilized with live steam every seven days. In cleaning coaches and chair cars, the windows are raised, doors opened, and the car thoroughly blown out with compressed air at a pressure of about 90 lb. Next, the car is scrubbed and mopped, woodwork wiped down, the entire car dusted, and the nickel work on water coolers, lavatories, etc.,

cleaned and polished. The exterior of each car is wiped with dry waste. Mail and baggage cars are blown out with air and swept out and dry wiped on the exterior. The electrical-equipment repairs are made, batteries are flushed and overhauled, and repairs on generators, regulators, and light fixtures on all electrically lighted equipment are kept up.

CLEANLINESS OF TERMINAL

Cleanliness of the yards and surroundings of a terminal is of vital importance, and requires constant supervision.

FREIGHT CARS

Freight cars are the revenue producers, and for that reason should be given the best handling possible. Due to the keen competition for business, it behooves all concerned to see that the cars are not delayed unnecessarily.

In the Kansas City Terminal for the road with which the author is connected, about 1500 cars are handled every 24 hours through interchange, which means that a record of the condition of each car must be maintained. All trains are inspected for defects such as vertical or sharp flanges, draft rigging, brake rigging, condition of air-brake equipment, and the condition of the car in general. All trains are blue-flagged while inspection is made. On live-stock, green-fruit, and oil trains, inspection is not made on arrival in order not to delay the switching of the trains, and a careful study of that method has proved it to be not only economical, but to expedite the movement of trains as well. During the busy season from 6000 to 7000 cars are handled through this terminal in 24 hours, and this is done with 32 car inspectors, 18 car repairmen, and 16 car oilers. This terminal is an oiling station, and all box lids are raised and all cars oiled that need it.

All tracks in the train yards are equipped with air lines, and as soon as trains are made up, air is cut in, equipment tested, and necessary repairs and adjustments are made. The handling of red-ball loads, perishable loads, or stock cut out on account of bad-order cars demands immediate attention, and these are made ready to go on the first connection after being bad-ordered. This means the closest coöperation between the operating and mechanical departments.

All brasses, new or second-hand, are broached before being applied to cars. In handling this volume of business it is necessary to have and maintain a high standard of inspection and work; if this is done, cars will not be unnecessarily delayed, and wrecks and derailments due to defective equipment will be practically eliminated. The cause of the most worry on cars is due to hot bearings, notwithstanding the fact that our average mileage per hot box is 55,408. If certain conditions are carefully noted when inspections are made, a wonderful improvement will be brought about. Hot boxes may be divided into two general classes: first, those which run cool after repacking, and second, those which continue to run hot after they are repacked. The contributing causes are:

Packing not in contact with journal
Packing caked or glazed
Oil washed out of box by the use of water, snow, or ice
Insufficient packing in box
Box packed too tightly
Presence of abrasive or cutting particles in packing
Dry packing
Cut and seamy journal
Defective or broken brass
Bent journal or axle
Thread of packing under brass "waste grab"
Wiper on edge of the brass
Concentrated pressure due to improper fitting of brass, tapered journal or brass, brass not the proper size for the journal, or shelled-out lining
Truck out of square
Truck side frames out of line
Crown of wedge not having proper bearing in the box
Brass not fitting the wedge
Unequal distribution of load
Overload.

ORGANIZATION

The supervisory forces in constant contact with their workmen represent the management, and should be carefully educated and trained in the proper handling and understanding of human nature. It is their duty to show a personal interest in the affairs of the men working under their direct supervision. As is well known, good will and confidence of each individual workman will bring the results that are most desired. The training and educating of foremen should not be overlooked. The officer in charge of a terminal or shop who does not give time and thought to the training of men under him, is failing to function for the best interests of the company for which he works.

In criticizing, it should be carefully noted that it is constructive, and not destructive, criticism that counts. This is vital. Each foreman should be given the authority to handle his work, and should then be held responsible for the results. When he needs help and advice, it should be given in a way that will make his efforts more effective. One of the most effective means of educating supervisors is for the officer in charge of the terminal or plant personally to check the work that the supervisor is being held responsible for, and if any irregularity is found, call his attention to it, explaining carefully what should have been done, bearing in mind not to be too eager to criticize unless there is some solution to offer.

SHOP-COUNCIL MEETINGS

To keep the workman or employee in the right frame of mind is essential, and this can be done by keeping his surroundings pleasant, as well as by keeping the plant or terminal clean and attractive. The author's organization has a shop-council meeting every month where supervisors and employees meet together to discuss all matters of interest that may arise, and these conferences have brought about wonderful results. One month a supervisor will be chairman of the meeting, and the next month a representative of the shop crafts will preside. Every complaint or suggestion is handled to conclusion, and stenographic records are taken of these meetings.

As many as seven hundred people have been in attendance at these shop-council meetings. The meetings are also made attractive by having some prominent man of the vicinity to make a talk.

The author's company has provided for the workmen a building in which are shower baths for the men, lavatories with running water, hot and cold, individual steel lockers for each man, and a lunch room with large tables and seating capacity for all. Also, in in this building, is the apprentice schoolroom where apprentices and future supervisors are trained for the trade they desire to follow. The employees receive their checks on company time and in the shop buildings. All machines are safeguarded to protect the employees, and a safety committee representing all the shop crafts meet bimonthly and go over all conditions, rendering a report to the management. Each item brought up is carefully considered and handled.

FIRE DEPARTMENT

The fire department is of vital importance to a terminal of any size, but more so to a large terminal where the management has millions of dollars invested. The author's company provides a fire chief for day service with twelve men under him. They perform other duties and do not serve full time in the fire department, but they have regular fire drills, and the fire chief has regular periods of inspection to see that the fire rules are enforced.

At night an assistant fire chief and eleven men perform regular service in the shops, but have fire drills and practices at regular intervals. A fire station with three men sleeping there at night is provided with fire watchmen on duty from 4 p.m. to 8 a.m. who carry a standard watchman's clock that is punched regularly, and this is checked each morning to see that they are on duty at all times.

PERSONNEL

The personnel of the mechanical department at a large terminal must be correspondingly large, owing to the volume of business handled, in a majority of cases, in a short specified time.

The division master mechanic has charge of all mechanical department matters, and is responsible for the furnishing of loco-

motives for switch service, passenger, and freight trains. He must also see that the cars are furnished in suitable condition to move the tonnage required without delay. He has three road foremen of engines to assist him by coöperating with the terminal organization. They can be a big help in keeping the power in proper condition, as well as in seeing that the locomotives are operated economically.

Locomotive Department

The following is the day organization in the locomotive department:

A general locomotive foreman has jurisdiction over all locomotive matters. The roundhouse foreman is very essential, as he has great responsibilities. He must be a quick thinker, and a man who can say "yes" or "no," knowing that he is right.

The assistant roundhouse foreman has charge of the outside, seeing that the locomotives get in the roundhouse promptly, and that they leave the roundhouse pit tracks on the time they are ordered; also he checks the power to see if repairs are properly made.

The machinist gang foreman reports direct to the roundhouse foreman. The author's company has one in charge of the work on freight engines, one in charge of the work on passenger engines, and one in charge of the work on switch engines.

The locomotive-air-brake foreman has charge of all the air work and stoker work.

The tender-truck foreman, pipe foreman, and painter foreman handle the work in the roundhouse and in the erecting shop.

A general boiler foreman and two boiler gang foremen must be provided in the roundhouse.

For the night organization in the locomotive department there is a night roundhouse foreman, who has an assistant roundhouse foreman with the same duties as the day assistant roundhouse foreman.

One machinist gang foreman on freight engines, one on passenger engines, and one on switch engines, tank work, and engine-truck work, are provided.

Two boiler gang foremen are responsible for all boiler work.

In the erecting shop are the erecting-shop foreman, machine foreman, and shop-apprentice instructor. The general boiler foreman, painter foreman, and pipe foreman handle their men in the erecting shop in addition to roundhouse.

The blacksmith foreman handles the blacksmiths in the locomotive and car departments.

The power-plant supervisor has jurisdiction over the boiler and engine room, and is held responsible for proper maintenance.

Car Department

In the car department, the general car foreman and the assistant general car foreman have jurisdiction of all car matters, reporting directly to the master mechanic.

One freight-car gang foreman and one car apprentice instructor are on duty in the heavy-car repair shed.

One freight-car gang foreman is provided on the light-repair track.

Two freight-car gang foremen have charge of the work in the load shed where red-ball loads which demand quick handling are repaired.

One wrecker foreman assists on the light-repair track when not on the wrecker.

Three assistants to car foreman do all the writing up of work cards covering repairs to be made.

One car-air-brake foreman looks after all air work in the car department.

Four train-yard foremen, two day and two night, and one interchange foreman are provided.

In the coach yard, on day work, are one coach-yard foreman, one coach-cleaner foreman, and one electrical foreman in charge of all axle light work. On nights there are one coach-yard foreman and one coach-cleaner foreman.

This personnel, as enumerated above, in the locomotive and car departments is in charge of a terminal that turns out 100 locomotives, 125 passenger cars in 24 hours. About 6000 freight cars also receive their attention per day.

In conclusion, one of the problems in every organization, large or small, is the man who knows a lot of things that are not so. The author's observation on this is that the thing a man is "down on" is generally something that he is not "up on," and that opens a very wide and expansive field for whatever educational effort one may care to make. This is the best world any of us ever lived in, and if we are Americans, our homes are in the best country in the world. With that much of a start, the author claims that no American has any right to complain about anything; because, if he is willing to shoot straight, if he is willing to sweat a bit, if he is as willing to give as he is to grab, his ultimate success will be beyond his dreams of today.

Discussion

L. K. SILLCOX[2] wrote that in emphasizing the importance of the stores department there was a possibility that it might not do so much as could be expected of it in providing the mechanical department with the necessary materials, because if it would run with a low inventory and place the whole burden for not having material on the mechanical department, when it at the same time had a full understanding as to the prospects of delivery of material when ordered which the mechanical man should not be expected to visualize, it might make quite a record at the expense of the railway company. It should be appreciated that the mechanical officer in charge was the predominating influence, and the stores department should be subsidiary to him as it was a service department of a secondary character, in other words, two steps from the actual operation, the first step being the mechanical man, who was dependent on two elements, labor and material, and the stores department assisted him in the second element. Shortage of material always cost a railway a great amount of money, particularly in shop operation, and more shortages were generally experienced where a low inventory obtained. It was the duty of the stores department, based on the best information it had, with a view of protecting a railway's interest to a maximum degree, to determine what amount of inventory should be carried to provide the mechanical department with standard materials.

One of the first essentials for economical operation had regard to minimizing, in so far as possible, the number of terminals a railroad should operate, yet this would not be accomplished successfully unless the minimum number of terminals were in such a condition as to be able to absorb the work required of them without penalty to the railroad. Railroad operation divided itself into two classes: first, actual performance of transportation; second, preparation therefor, and the latter was involved in terminal operation. A railroad began to produce transportation when it started making revenue train-mileage, and only then did it begin to earn money. All other work done by a railroad was of a preparatory character and was not directly remunerative, though it might be very expensive. Only recently he had learned of a railroad which had minimized the number of terminals and modernized those which remained, with the result that foreign cars for which a dollar a day was charged between railroads remained on the company's line four days in place of twelve days as formerly was the case. This was a saving of $8 a day alone in rental expense, to say nothing of the better service made possible to the shippers, and the more economical and simplified operation for the railroad itself. The principle involved in this case was one of utilization, and it affected all classes of equipment, and was especially far-reaching in the handling of locomotives.

In so far as power plants were concerned, Mr. Sillcox had found it important to emphasize the matter of protection against breakdowns, because even with the best of maintenance unforeseen conditions obtained. A breakdown in a power plant practically meant a shut-down of a shop or terminal, and most of these operations involved a 24-hour service requirement. Extensive studies had been made to determine the efficiency of the power plants of the C., M. & St. P. Ry. with a view of measuring this factor against the possibility of the purchase of electric current from an outside source. In some cases the power plants had been modernized because of local necessities, involving individual decision at

[2] Gen. Supt. of Motive Power, Chicago, Milwaukee & St. Paul Railway, Chicago, Ill. Mem. A.S.M.E.

each point based on the service requirements. In other cases it was found advantageous to purchase power, and studies were under way with a view of doing away with the requirements for steam in locomotive power plants during the summer months, through the use of electric fans for firing up engines.

Another important feature to consider involved the matter of fuel supply for power plants, first, with a view toward having the operation as economical as possible, and second, making the selection with a view toward improving locomotive coal. By burning screenings in the power houses it was possible to get lump coal for passenger engines.

Much study had been given to the division of responsibility between what was generally termed the roundhouse inspector's report on a locomotive arriving at a terminal and that which was received from the locomotive engineer. The report required of an incoming engine involved certain road operations which a road engineer could obtain, such as the following:

Pounds
Brakes not properly responding
Leaking cab cocks
Dirty water glass
Leaky water-glass drains
Leaky piston or valve stems
Safety valves not registering properly, etc.
Gage cocks stopped up
Loose gages or brackets
Air gages registering improperly
Defective reverse lever
Leaky cylinder and valve heads
Inoperative cylinder cocks

Other items which needed to be observed on an incoming engine were closely followed up by the roundhouse inspector as follows:

Tests within specified period
Leaky joints
Piston travel
Loose or missing parts
Cab cards

Worn crossheads, guides, piston or piston rods, cylinder cocks or rigging, dome caps, draft gear, ashpan, blow-off cocks, boiler checks, driving-box shoes, wedges, gage cocks, hand-holds, injectors, packing, tires, etc.

The periodical inspection of locomotives referred to involved strict assignment of responsibility. Each engine must be, as it were, owned by some master mechanic or some roundhouse foreman. The keynote to the success of any plan hinged around the problem as to what kind of service would be accepted from the locomotives by the management. If perfect service were demanded, and no excuses for failure to give it were allowed, then the result would be a fair division of the work; and undoubtedly the monthly inspection system had much more to its credit than any other program, because, in the first place, each locomotive was required by law to be inspected in this cycle, and while it was being held, all of the work that could be anticipated as required for a month's operation should be taken care of before the locomotive was released for further service; and if this work was properly followed up in detail for each trip, a locomotive would not be in such condition as to fail immediately after this before the next monthly inspection. Proper limits of wear should be carefully worked up and determined beyond which a locomotive would not be released after receiving a monthly inspection. A number of railroads, including his own, had made a very thorough study of these features, but it would involve a paper in itself to set them down.

Passenger cars and freight cars were referred to by the author only with respect to routine terminal operation. It was usual practice throughout the country to give passenger cars classified repairs in back shops every 18 to 24 months, and freight cars about every 8 to 10 years. The author had covered the cleaning operation and transportation attention to rolling stock with regard to lubrication, etc., very fully, and the practice referred to was followed with slight modification, depending upon service requirements, on all railroads, especially on freight cars because of the necessity of their use interchangeably between railroads.

B. P. Phelps[3] said that the modern locomotive had been brought to a high standard of efficiency by the use of such appliances as the feedwater heater and superheater. While these increased the cost of repairs, they greatly decreased fuel consumption. Fuel conservation was receiving great attention by the railroads, and firemen were being checked up and instructed in the matter of fuel waste.

Railroad discipline was necessarily severe because of the disastrous consequences of errors. Railroad men had to know by experience and judgment what was necessary for the safe operation of the road, and had to see that men under them followed instructions rigorously. It was particularly necessary under these conditions that cordial feeling should exist, that working conditions should be attractive, and that apprenticeship systems should be fostered for the good of the personnel.

Wm. Elmer[4] said that on the Pennsylvania lines the master mechanic did not control the road foreman of engines directly, except that they were subservient to him when in his territory.

The Pennsylvania had much trouble with hot boxes, there being as many as twenty-five to thirty a day in east-bound traffic on the division between Altoona and Harrisburg. He said that on the Pennsylvania they cleaned the fires instead of knocking them, by which he understood Mr. Harrison to mean that the old fires were dumped and new ones kindled.

In connection with fuel conservation he had recently investigated a flotation scheme for recovering coal from ashes. He thought that fifteen or twenty per cent might be recovered from locomotive ashpits by such a method.

Roy V. Wright[5] spoke of the improvements in railways and railway operation which had marked the past few years. The engineer had done much to bring about this improvement. Remarkable progress had also been made in management, which had been reflected all the way down the line and had resulted in handling more traffic with fewer locomotives and freight cars than ever before.

In closing the discussion, the author said that the road foreman on the Santa Fe was carried on the master mechanic's payroll, was responsible to him for anything connected with locomotive handling, and reported to the superintendent any violation of operating rules. Most trouble with hot boxes was on cars belonging to private tank lines. On the Santa Fe, boxes on all cars were packed every six months. The greatest trouble was in the packings' getting away from the shoulder of the journal. It required constant supervision to be sure that inspectors and oilers used the packing hook for the purpose for which it was intended. A properly trained man could tell whether the journal was cut or not by raising the box lid and running the hook lengthwise under the journal. On the Santa Fe, fires were cleaned on locomotives on long runs over one or more divisions, but at final destination fires were knocked regardless of whether the engine was to double back in a few hours or not.

Arrangements have been completed whereby the students of the course in Fuel and Gas Engineering of the Massachusetts Institute of Technology will do field work and testing at the Edgar Station of the Edison Company of Boston. This course is intended to train graduate engineers in the theory and practice of fuel utilization, gas manufacture, and power generation. The work consists of one academic year of graduate study at the Institute, followed by six months' field work. In this field work the theoretical side of Fuel and Gas Engineering studied at the Institute is applied to the actual processes of combustion, gas manufacture, and power generation and oil refining by plant studies and tests on full scale equipment in commercial operation—all carried out under the immediate supervision of a member of the Institute faculty.

The Edgar Station contains prime movers operating at both 1200 and 350 lb. steam pressure and is equipped with a very advanced type of combustion control. These factors alone evidence the remarkable opportunity which the students are afforded in observing, through study and test work, the detailed working of this central station.

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[5] Editor, *Railway Age*, New York, N. Y. Mem. A.S.M.E.

Mechanical Engineering in Flour-Mill Operation

A Brief Account of the Mechanical Engineer's Relations to and Accomplishments in the Milling Industry

By M. D. BELL,[1] MINNEAPOLIS, MINN.

FOR THE purposes of this paper, flour-mill operation can be divided into five major divisions: (1) Grain storage and handling; (2) milling; (3) packing and loading; (4) mechanical department; (5) related activities.

Grain Storage and Handling

Grain storage and handling in a large milling organization is far removed from the simple matter it used to be when the farmer carried his sack of grain to the mill, watched it being ground, and received it back again as flour and feed. This department now represents the combined activity of many men in a widespread organization operating over many states. It studies prospective crops and market conditions. It requires careful sampling, analysis, and testing of the grain before purchase. Elaborate systems of inspection, weighing, and supervision of unloading have been developed by state authority in the grain-growing regions for the assistance of the grain grower and purchaser.

Modern American grain-handling methods, transportation, unloading, and storage show an amazing advance over the primitive methods still in general use in other parts of the world. Bulk handling of grain has reduced cost, added speed, widened the markets, and facilitated the financing of crop movements.

When the wheat is unloaded, it is placed in separate bins according to analysis, protein content, or other qualities affecting milling value. Wide variation in the characteristics and the supply of wheat requires careful blending to maintain uniform quality of flour. Wheat is shipped to the mills as required and is carried on an endless conveyor belt. The wheat is weighed en route by means of automatic grain scales as accurately as if it were being sold to another concern.

The construction of modern concrete elevators is a special field, more correctly belonging to structural or civil engineering, but in the design of the facilities, installation of the equipment, and the maintenance and operation of these elevators, mechanical engineering has a part.

The car dumper for unloading bulk cars of grain is a new device for large grain elevators. It represents the achievement of much mechanical-engineering effort. It offers a mechanical means for tipping the car sideways and endways, allowing the grain to run out of the side door, into the handling equipment below. It will eliminate shoveling, heretofore the best means available, but hot and dusty work and objectionable to men able to find any other employment.

The weighing of grain has demanded much engineering attention, and modern equipment is accurate and well adapted to the rapid handling required. It is of three types, the track scale, the large hopper scale, and the automatic scale. This last is a modern development that has opened up many new possibilities in handling, and is also used extensively for weighing flour.

Milling Operations

Milling operations begin with grain cleaning and preparation. Seeds and impurities are removed by special screens and many different types of separators. Dirt or smut is removed by washing and by scouring. Moistening the grain and allowing it to stand in the bins for several hours, tempers the wheat and toughens the outside coat of bran, thus assisting in grinding and in the separation of the parts of the wheat berry.

Grinding is now done universally on the roller mill, which superseded the buhr stones used up to 1870. The milling system now used is known as the "gradual-reduction" process, introduced into the United States from Hungary. It is still frequently described as the "Hungarian" or "patent process." Previously, flour was produced in one operation, on one run of stone, and the product was dark, because mixed with finely ground bran. The gradual-reduction process requires many stages, gradually grinding finer and finer. After each grinding, the product is sifted to remove the bran. The flour thus produced is clean, attractive in appearance, and has improved keeping and bread-making qualities.

The sifters used for sorting the flour particles are of many varieties. The "plan sifter" was of European origin. The centrifugal reel was developed for sifting very fine flour that is too light to pass readily through the fine meshes of silk bolting cloth in the quantity required in large mills. Round reels are used for another type of work. The bolter or vertical self-balancing sifter now in general use is a strictly American development. It handles a wide variety of work with precision in grading and is easy to adjust and to keep in repair.

The purifier is a machine used to remove particles of bran from the coarse middlings, which are at the stage of grinding resembling

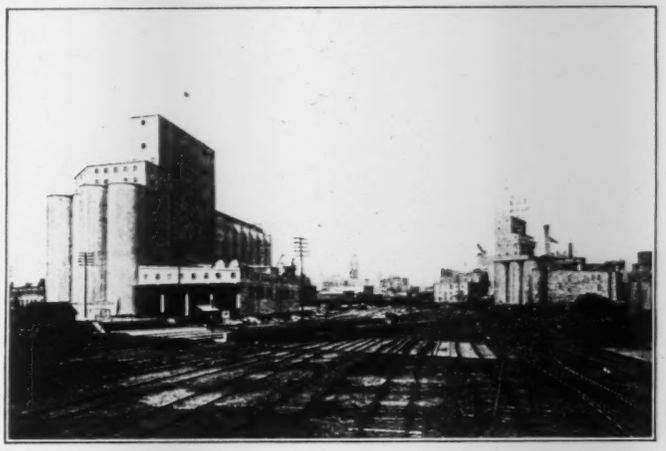

Fig. 1 West Side Milling District, Minneapolis, Minn., Showing 2,500,000-Bu. Grain Storage Elevator with Unloading Shed

"Cream of Wheat." By making use of the difference in specific gravity, the light bran particles are separated from the heavier flour middlings which fall through the current of air that is drawn up through the purifier sieve. The purifier made modern white flour possible.

Milling operations in each mill are under the direction of a head miller with a crew of highly trained men. The value of the product runs into big figures in a mill grinding as much as 50,000 bushels of wheat every twenty-four hours. The quality and the value of the flour depend on the judgment and skill of the miller more than on any other single factor. He makes use of the information obtained through the laboratory, the experimental mill, and the mill bake-shop, and is guided further by reports that come to him through the company's service men in contact with their customers in the large commercial bakeries. The head miller of today is a man of wide information and scientific knowledge. In the operation of milling plants, the requirements of the milling division are rightly given primary consideration, and all other activities must be made to work in complete harmony with this branch.

Packing and Loading Department

The packing and loading department takes the products as they are put in the bins by the milling division and packs them for the trade. There are many products, and many sizes and kinds of packages. The wooden barrel formerly used is now nearly obsolete except for export to the tropics. The cotton or jute sack has taken the place of the barrel, but the unit of measurement still remains as a reminder of the past. The sack is cheaper, more convenient to handle, and has more salvage value. Some large bakers, dealing

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Presented at the Kansas City Meeting, Kansas City, Mo., April 4–6, 1927, of The American Society of Mechanical Engineers.

directly with the mills, furnish their own sacks, and they are used many times, being returned to the mills, cleaned, refilled, and sent back to the baker with a saving in cost.

Modern living conditions have changed the packages used for domestic trade. The 98-lb. or half-barrel sack is seldom carried home. Instead, the 1/8-bbl., or 24 1/2-lb. sack, is the popular size. In the big cities, with the increase of small apartments, there has been a growing demand for packages from 10 down to 2 lb., in both cotton and paper containers.

The packing of these many sizes in large quantities has necessitated the development of automatic weighing and packing equipment, also the invention of many entirely new machines for sewing or tying them. The accuracy and speed of operation, and the reduction in packing expense, are all responsible for the delivery of flour to the customer at a remarkably low cost over the price of the raw material.

Mechanical package handling has come into prominence in flour mills in recent years. Conveyor belts, boosters and elevators, car-loading equipment, and special machinery of many sorts have been invented and installed widely for flour-mill use.

MECHANICAL DEPARTMENT

The mechanical department is concerned with plant design, power, the installation and maintenance of machinery, and incidental matters pertaining to operation. Here the mechanical engineer is in his own field.

Power was the earliest engineering requirement. Water power was first in use, and its development was often of sufficient importance to determine the location of the mill.

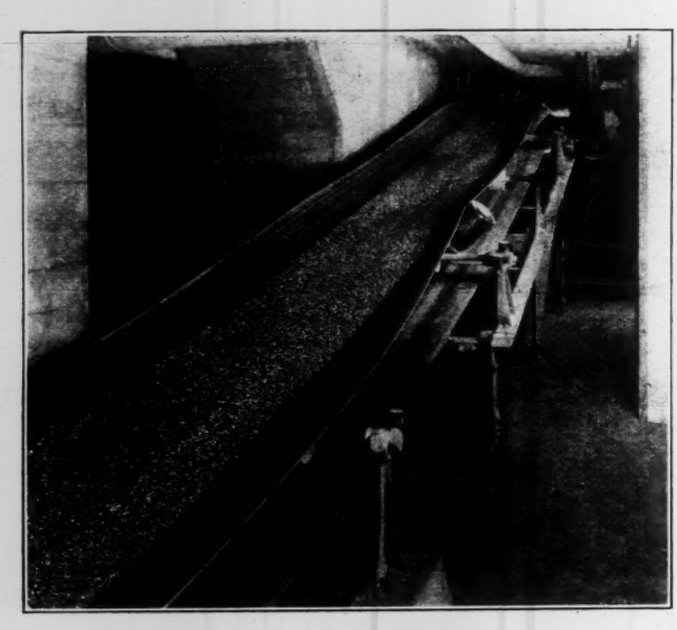

FIG. 2 GRAIN CONVEYOR BELT USED IN GRAIN ELEVATORS AND FOR SHIPPING WHEAT TO FLOUR MILLS

At St. Anthony Falls, local conditions made it possible to install the water wheels in pits under the mill floors. These pits connect with tail-race tunnels under the limestone ledge, carrying the water out to the river again below the falls. The vertical type of water wheel was usually the most convenient at Minneapolis. It permitted the shaft to be connected with the main mill line by means of bevel gears, one of each pair having mortise or inserted teeth of maple. Many of these gear drives are in every-day use at the present time.

The vertical bearings on these water wheels have always presented a problem. For years the weight has been carried on a vertical step bearing submerged in water in the draft tube under the runner. The bearing consisted of a step or concave on the vertical shaft resting on a button of either lignum vitae or vertical-grained white oak. The development of the Kingsbury type of thrust bearing was quickly adapted by flour-mill engineers to use on these water wheels. The bearing is located at the top of the shaft under the driving gear and the entire weight of shaft and water-wheel runner, including the dynamic thrust of the water, is carried from this new suspension bearing. These bearings have successfully stood the hammering of the gears and have required little maintenance. They have also been used in new hydroelectric plants installed for flour-mill service using direct-connected umbrella-type generators.

Belts were early in use for main power transmission. Later, rope drives came into favor because of the convenience with which power could be transmitted from one shaft to several on higher floors when using the American system of rope driving.

FIG. 3 ROLLER MILLS ON GRINDING FLOOR

As milling capacity increased and business expanded, the seasonal limitations imposed by water power became more and more objectionable. Steam power was installed first as secondary power, to carry over the winter months or periods of low water. As demands increased, and water power was not available, or was not economical to develop, steam grew into wider use.

In the boiler room new types of boilers have been added as developments have showed them to be economical. Steam pressures have been raised, new types of stokers installed, proper auxiliaries provided to insure continuous operation, and feed-water heaters and softeners, economizers, and superheaters utilized to the degree that the local load factor justified. With coal consumption in some plants reaching over two hundred tons of coal per twenty-four hours, combustion economy was studied and instruments in use in modern central-station plants have been used in flour-mill boiler rooms. In recent years, as the central stations have sought to obtain flour-mill contracts, the mill steam-power costs have caused surprise and favorable comment.

The engines first used were of the high-speed, slide-valve variety. Later, Corliss engines were installed, compound and triple expansion in sizes up to 3000 hp. The practice has been generally to run condensing. At Minneapolis the barometric condenser has frequently been employed because of its simplicity, lack of maintenance, and the high vacuum obtainable with unlimited cold water available in the winter time. The method of installation was unique, as in most cases the condensers could be located near the river level so as to lift their own condensing water and the tail pipes could discharge into the tail races below with a free fall of nearly 50 ft. Surface condensers have been used only for such units as would operate throughout the year.

Steam turbines have been used successfully by flour-mill plants in sizes up to 2000 kw., both for generation of electric power and for direct connection to the main lineshaft, through reduction gears of the herringbone type. Some combination installations have been made in which steam has been used at high pressure in an engine or turbine for developing power, and then exhausted into the low-pressure steam mains for heating and drying. This is of value especially where the steam is supplementing water power when the period of low water occurs normally in the winter months and steam heat is required.

Diesel engines have a field in flour-mill work, especially in regions remote from water power, and where reliable central-station power can not be had, or is sold at a rate that is not properly figured to compete with flour-mill costs on their unusually high load factor.

Electric power has won its own field of application in recent years as primary power in many milling plants and in others as secondary power to supplement the available water power. Flour-mill electrification has been recently covered in detail in a paper

presented before the American Institute of Electrical Engineers in Kansas City by Mr. Grover C. Meyer, and discussed from the mill-operation standpoint by the speaker.

The application of electric power to flour-mill work and elevators has added new possibilities and convenience to mill design. Transmission of power from the motor to the load has been by belt, rope, gears, chains, and frequently by direct connection. Where flexible couplings are required, modern developments provide

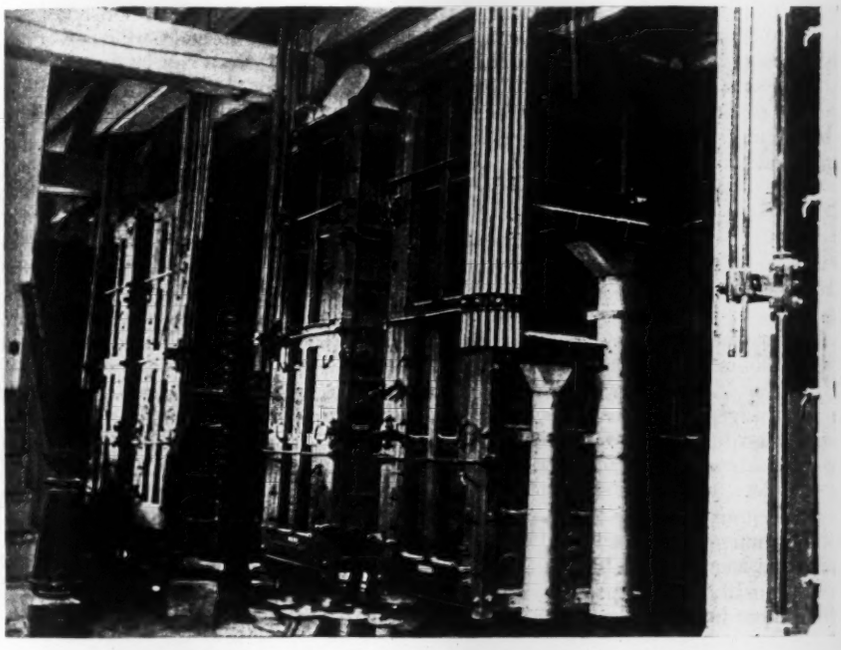

FIG. 4 SELF-BALANCING SIFTERS USED IN MODERN MILLS

several of new and substantial design. Magnetic clutches have been used with complete success in starting flour-mill loads, particularly where synchronous motors are installed for power-factor correction. Another combination of interest to mechanical engineers is the supersynchronous motor, which makes use of a mechanical brake of the Lidgerwood type, operating on the stator which is allowed to spin during the starting period.

Ventilation, heating, and drying of washed wheat are closely related to the steam department. Refrigeration is necessary for drinking water and cafeteria ice boxes. Humidity control has been of recurring interest in flour mills, and may some day go far to remove the effect experienced in reduction of capacity under change of weather conditions, if some means can be found to accomplish this at moderate expense.

Plant design is of primary importance. The mechanical engineer, working with the operating heads of the departments concerned—milling, grain handling, or packing and loading—prepares plans to meet the special requirements, applying the principles of analysis, machinery knowledge, and mechanics with the materials that are available. He must keep the practice of the particular plant in mind, accommodating the design to meet personal preferences, as well as changing conditions due to crops, the expected life of the installation, or local conditions.

Construction of buildings is closely related to the work of the mechanical engineer. There must be close study of the machinery requirements. Usually in designing a new mill, it is the practice for the head miller to indicate the number and size of the machines required to produce the capacity or number of barrels per day, and then to fit the building around them.

Maintenance is a large field for mechanical engineering in plants with capacity of 15,000 barrels or more per day. The mechanical superintendent is in charge of separate shops for repair work that compare favorably with commercial jobbing shops in size, equipment, and quality of work. Incidentally they frequently manufacture special equipment for the plant, or such items as can be stored in the supply room. The primary object of these shops is to be ready to take care of emergencies and breakdowns, or to aid in quick repairs when a mill is idle for any reason. Their chief purpose is to keep the mills running, and many interesting incidents could be given of unusual work done in them.

The grinding and corrugating of the chilled rolls used in roller mills is one of the most important jobs done in the machine shop. The work is done with great accuracy. There are many different cuts that are specified by the head miller for various kinds of work in grinding the wheat, or for different kinds or conditions of wheat. The roller mills operate with a differential, one roll in each pair running faster than the other, so that each roll must be cut with this in mind. Part of the work is done on smooth rolls, ground accurately so that they are in proper contact with the flour being ground when at the higher temperature that they reach when grinding.

The carpenter shop is a busy place, not only on building maintenance, but in the manufacture of special machinery using wood. The millwright shop is primarily concerned in placing and repairing the machinery used in mills. When new construction is under way, the millwright crew is increased in number to take care of the extra work. Patternmaking is another activity of this department, covering special castings required or designed by the mechanical department.

Sheet metal is used extensively for spouts, wind trunks, elevator cups, conveyors, and numerous other purposes. A well-equipped sheet-metal shop is necessary, with shop machines and portable tools for all sorts of sheet-metal work.

Belts in flour-mill work are mostly of leather and made endless by gluing the joints. A belt crew is engaged in repairing and caring for belts. Special belts of cotton or rubber are used for elevating the mill products. These use mechanical fasteners. They carry sheet-metal cups of various shapes and sizes.

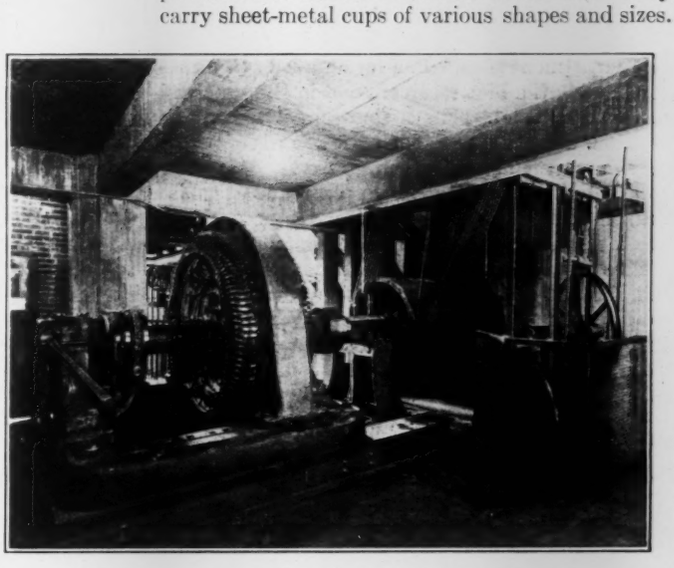

FIG. 5 1000-HP. INDUCTION MOTOR AND ROPE DRIVE FOR 3500-BBL. FLOUR MILL

Electrical operation and maintenance are under the care of trained electrical operators and repair men. Motors are rewound, bearings replaced, and major operations carried through successfully within the plant.

Piping, water supply, sewage systems, sprinkler equipment, heating systems, fire protection and alarms, supervisory and other automatic recording equipment require the services of other crews under the mechanical department.

Dust collecting was one of the early problems that confronted milling engineers at Minneapolis. The explosion of the Washburn "A" Mill in 1878 made history. There had been dust explosions elsewhere before this, but of no such magnitude, nor attended with such loss of life. Governor Washburn was a man who wanted to know the facts. He investigated and employed engineers to study

the subject. He applied all that he found that seemed accurate and of value. Experiments were made to show under what conditions dust would explode. It resulted in the design of dust-collecting equipment of many varieties and in fire-preventive measures. More is being learned all the time. Engineers engaged in flour-mill work have been consistently interested in the solution of the dust-explosion problem.

Fire prevention and safety cover a large field in flour-mill practice. Much special equipment is required, with regular inspection and maintenance and frequent tests. Pumps and water supply are duplicated. Sprinklers are kept in service at all times. Fire doors and other cut-offs are properly maintained. Cleanliness is insured by regular sweeping and by dust-collecting equipment. Drills help to familiarize employees with the significance of fire alarms and the location of call boxes, and train them in the use of equipment. Suggestions for safety are solicited from employees and coöperation is encouraged.

Related Activities

The division of related activities in plant operation includes the personnel department, the purchasing department, the insurance department, and the cost department.

The personnel department hires new employees, assists in their training, looks after their interests in matters of insurance and first-aid treatment in case of accident, keeps records required for the service of the employee, handles time keeping and payment of wages. In plants where employee-committee systems are in operation for mutual discussion of matters of interest, this department assists in representing the management. In every possible way this department supplies the human contact that a large organization must maintain to insure the fullest understanding and coöperation of all the employees and the management. Wages are adjusted from time to time as business conditions or the cost of living may justify.

The purchasing department looks to the mechanical engineer for specifications on technical purchases, inspection, information as to performance, and recommendations on quality of materials to be used. In contracting for extensive construction work, the mechanical department is called on for detailed specifications, assistance in considering the bids received, and in the supervision of work when the contract is let. The engineer must be familiar with contractual relations and must keep adequate records of performance, and must pass on payments as work progresses.

The handling of stores, supplies, and surplus equipment, as a branch of the purchasing department or otherwise, is of interest to the mechanical department, and contributes to efficient operation.

The requirements of the insurance department are served by mechanical appraisals, checked up at regular intervals with additions and deductions for changes. Valuations, depreciation, and adjustments in case of loss are computed in the engineering department. Information is also compiled here for use in the preparation of tax statements.

The cost department puts operating expenses in proper form for the mechanical department to use in making decisions governing plant operations. Comparisons are made between plants, or between departments, where this is of advantage to show efficient work or to suggest improvements possible. On special jobs, accounting is required for charges to other plants or departments. Just as the manufacturer must have accurate costs to enable him to compete with other plants, so the mechanical department requires a sufficient analysis of its operating expense to enable it to work intelligently and to handle the wide variety of its responsibilities with satisfaction to all concerned.

The present tendency in flour-mill practice seems to be toward concentration in larger groups, with less opportunity for the small mill, except those that can be satisfied with only local trade. The problems in these larger companies appear to lie not so much in organization or in mechanical operation, but more in the welding of one harmonious group out of a large number of individuals, who by training and tradition have been very independent, like the "Miller of the Dee." Engineers who understand this situation, should be able to adapt themselves to it, and assist in a development that is doubtless inevitable.

Standardization of mechanical products has gone far, with benefit to consumers everywhere in lowered cost and better quality. Standardization in production methods will undoubtedly follow, and mill operation will reflect more and more of this progress. While flour is now more uniform and of higher average quality than ever before, by further standardization its quality can be maintained more easily, with fewer variations demanded by individual big purchasers, and with reduced costs in manufacture and in distribution. This change is primarily the concern of others, but engineers can assist in it by helping to show the public that standardization means high quality, uniformity, and low cost, rather than some limitation of freedom or departure from some cherished practice of a by-gone past, that cannot be accurately described except as sentimental nonsense and gross waste.

The past fifty years have shown a remarkable change in milling methods. New ideas have come and millers have been quick to adapt themselves to them. We have seen the change from the buhr stone to the roller mill, from the old quick-reduction process that made dirty flour to the gradual-reduction process that makes a product that is clean and wholesome. We have seen a change in management from the small mill-owner type of organization to the large corporations that operate in many cities with the world as their market. The study being given today to improved methods, in management, in distribution, and in operation, must mean further progress and increased benefit to all in the milling business and to the general public.

Mechanical engineers have contributed to milling progress in the past. By thoughtful study of today's conditions, and wholehearted coöperation with all others involved, they will undoubtedly contribute to further progress and substantial advancement.

Airplanes for Commercial Aviation

ALTHOUGH the speed of commercial airplanes is a very important factor, they offer, in addition to speed, safety, and comfort in the form of roomy cabins equipped with all the necessary things that are provided by railroad trains, including a heating system, a ventilating system, glass windows that can be opened and closed, and an aisle with room to walk between the chairs.

The safety of operation of airplanes is not merely a question of construction but of ground organization. The Government furnishes lights, maps, and radio service to enable vessels that travel along the coast to complete their voyages safely, but it has not yet furnished the ground service needed by commercial airplanes. Landing on the fields at night is one of the greatest problems.

For safety of operation, a good system of weather reports is necessary. The moment he starts, the pilot should know what the weather is along his entire route, and if there are adverse changes in the weather, he should receive the information during his flight by telephone, radio, or signal, so that he can return to his starting point or can land elsewhere than at his intended destination. To produce really efficient service in long-distance flying, a kind of block system, or a radio or telephone system, should be provided, so that the pilot can be communicated with at any moment and at any distance. Such systems are used on many of the airplanes crossing the English Channel from London to Paris and Amsterdam.

The extreme importance of night flying is causing intensive study to be made of the several problems not yet solved that will make possible safe operation at night during periods of thick weather and poor visibility, and when high mountains must be crossed. Intensive work is being put upon the development of instruments that will enable a pilot to keep his course and determine the position of his airplane in the air even though visibility is totally lost.

It is possible to build airplanes now that will not fall suddenly or cause the pilot to lose control even though the airplane loses speed. If stalled in the air, a modern airplane will not go into a sudden uncontrollable nose dive or tail spin, but will settle slowly on an even keel and the pilot can keep perfect control.

Three engines are used in the large airplanes, because the failure of one reduces the available power by only one-third, and will not necessitate a forced landing. The smaller the number of engines used, the larger they must be to maintain flight under conditions of emergency, and the larger the engines are the greater is the proportion they represent of the gross load of the airplane, with consequent reduction in the pay load.—A. H. G. Fokker in *Journal of the Society of Automotive Engineers*, September, 1927, p. 250.

SURVEY OF ENGINEERING PROGRESS

A Review of Attainment in Mechanical Engineering and Related Fields

Four-Stroke-Cycle Diesel Engines of the Solid-Injection Type

THIS type of engine is described in the article here abstracted as a compressorless engine with jet atomization. The article deals exclusively with the types developed by the Linke-Hofmann Works in Breslau, Germany. There are essentially three types of these motors, namely, normal-speed, medium-speed, and high-speed. To the first class belong heavy motors with outputs of 50 to 1200 effective hp. at 167 to 250 r.p.m. These motors are used chiefly in electric generating stations and shops. A type of construction has been selected which gives a very considerable amount of rigidity and is yet quite simple. The fuel pump, which is described as the soul of this type of motor, works as a pure jet-atomization type. Its operation depends very materially on the elimination of such sources of trouble as warping, and for this reason the pump is bolted to the base plate close to the flywheel and is driven not by the camshaft but directly from the crankshaft through a gear transmission. Notwithstanding the necessity of using comparatively long piping between the pump and the injection valves, indicator diagrams show that very precise metering of the fuel oil to all the cylinders is attained. The governor is located on a vertical camshaft right next to the fuel pump. The pump starting valve and the device for relieving the compression pressure are all controlled from a single lever, the last-named device being of such a character that a motor can be started with gases at a pressure of 10 to 20 atmos. and such gases can be bled from the cylinders by means of a special valve.

Because of the fact that in some countries there is a preference for motors using compressors, provision is made to install one on this type of Diesel motor.

Medium-Speed Diesel Motors. The Linke-Hofmann Works build these only in the compressorless type. Constantly decreasing sale prices make it imperative to employ higher speeds, and this type of motor cannot be converted into a motor with a compressor because the end of the motor opposite that carrying the flywheel is entirely occupied by lubricating-oil and cooling-water pumps.

Because of the location of the horizontal camshaft close to the base plate, it can be driven from the crankshaft by a set of three gearwheels. There is therefore no objection in this case to driving the fuel pump from this camshaft.

In compressorless Diesel engines with jet injection the pistons have much less tendency to heat than in air-injection motors. Because of this it is only when the output reaches 175 effective hp. per cylinder that it becomes necessary to cool the pistons. When output per cylinder exceeds this, it becomes necessary to resort to piston cooling, and as it is difficult to cool the plunger piston, it became necessary to provide the pistons with a peculiar type of crosshead. The fuel-injection device shown in Fig. 1 works as a pure jet atomization.

For the success of the injection process it is necessary to use the so-called "closed" nozzle (Fig. 2 at left, patented in Germany) with at most five nozzle orifices completely covered by the needle cone. This device reduces to a minimum the tendency of fuel to dribble after injection, which is the cause of so much trouble in compressorless Diesel engines. The "closed" nozzle permits the employment of long ducts between the pump and injection valve, and the fuel piping in order to reach the most distant cylinder, is, in this case as much as 7 m. (22.9 ft.) long. Although the oil pressure is in such a case quite considerable, just as good combustion is secured in this remote cylinder as in the other cylinders, as is shown by indicator diagrams in the original article.

The oil pressure is regulated by means of the valve spring, and in the case of gas oil it is from 250 to 300 atmos. The needle opens under the influence of the oil pressure produced by the differences in the needle cross-sections. The nozzle behaves most favorably at small loads and when running idle, but where the needle cone is located ahead of the nozzle orifices, incomplete combustion occurs at low load or when the engine is running idle, this being indicated by a bluish exhaust. By properly displacing the nozzle orifices with respect to the nozzle cone, the exhaust may be made completely clear, even when the engine is running idle. The reasons for this good combustion are elimination of dribbling of oil and good atomization. At the same time, however, the injection orifices of this "closed" nozzle can be given comparatively large diameters. While in the case of an open nozzle without movable needle, or the half-open nozzle with the needle cone ahead of the nozzle orifices, the holes have to be from 0.2 to 0.35 mm. (0.0078 to 0.0137 in.) in diameter, in the construction here described the holes may be from 0.5 to 0.8 mm. (0.0196 to 0.0315 in.) in diameter, depending on the size of the combustion chamber.

When the engine is running idle (Fig. 2) the needle is lifted but a very slight distance. From the drawings of the oil jets it appears that the atomization of all the oil takes place at the inner sharp edge of the nozzle orifice. The higher the needle lifts with increase in load on the motor, the more there forms within the nozzle orifices a solid, not so finely atomized oil core. (Illustrated in the original article by a halftone, which cannot be satisfactorily reproduced here.) This is very important, because the oil core is the carrier of the energy imparted to the oil by the pump pressure; the larger droplets of the oil core have a greater force of penetration; they fly far into the combustion chamber and find there the oxygen which they need for their combustion. It is quite likely that this oil core produces a thorough turbulence in the combustion air and thereby helps to force the air within the range covered by the various fuel-oil jets. This is partly indicated by the high specific outputs which have been successfully attained with compressorless motors and pure jet atomization.

The lifts of the needle increase comparatively rapidly with increase of load. If the delivery of the oil is interrupted by opening the overflow valve on the pump, the atomization of the oil continues for a little while longer during the closing of the needle. The atomization becomes finer as the needle approaches its seat, so that a good combustion is obtained even in the air already partly used up. The flame draws back toward the nozzle orifice in the same way that it draws away from the orifices when the needle lifts. Attempts were made to limit the lift of the needle to a certain maximum value, but this did not prove very satisfactory and the best combustion was obtained when the spring-loaded needle was given free play.

With this kind of "closed" nozzle it proved to be best to keep the combustion pressure comparatively low, and this resulted in diagrams which were like those from compressor motors working with a constant-pressure combustion. The compression has to be higher than that admitted usually in compressorless motors operating with jet injection, this being done so as not to have the ignition pressure excessively high. High compression also insures good starting of a cold motor, as well as good combustion of heavy oils and particularly coal-tar oil used without lighter ignition oil.

Experiments are now being conducted with the idea of approaching the constant-pressure diagram in another way. It is a well-known fact that when the oil pressure is maintained at a certain given level or when a given amount of oil is driven through the nozzle orifice within a given time, the atomization improves as the orifice is made thinner. It has been already stated that as atomization improves, preignition and hence rise of pressure over the end pressure of compression may be reduced. Fig. 2 at the extreme right shows a nozzle in which the orifices are only 0.5 mm. (0.0196 in.) in thickness. This nozzle gives a diagram shown in the original

article and distinctly approaching a good constant-pressure-motor diagram. Unfortunately, because of their very slight wall thickness, such nozzles are apt to burst, but nozzle types are already being developed which have thin orifices and yet promise a long life.

The article reports further tests with a compressorless motor of the above type rated at 600 effective hp. for 214 r.p.m. These tests appear to have given very satisfactory results. Among other things are reported tests made with an Argentine crude oil of very considerable viscosity and a high asphalt content. (Chief Engineer Rudolf Mayer, of Breslau, in *Zeitschrift des Vereines deutscher Ingenieure*, vol. 70, no. 31, July 30, 1927, pp. 1081–1088, 28 figs., *dA*)

AERONAUTICS (See Internal-Combustion Engineering: The Kinner 5-Cylinder Air-Cooled Engine)

AIR ENGINEERING

The New Well System of Amarillo, Texas

THE former well system involved an unusually high cost of operation because of the wide distribution of the wells, high lift, and relatively small yield of water from individual wells. The new development comprised the drilling of seven large wells and construction of large reservoirs and pumping stations. An interesting feature was the development of the wells.

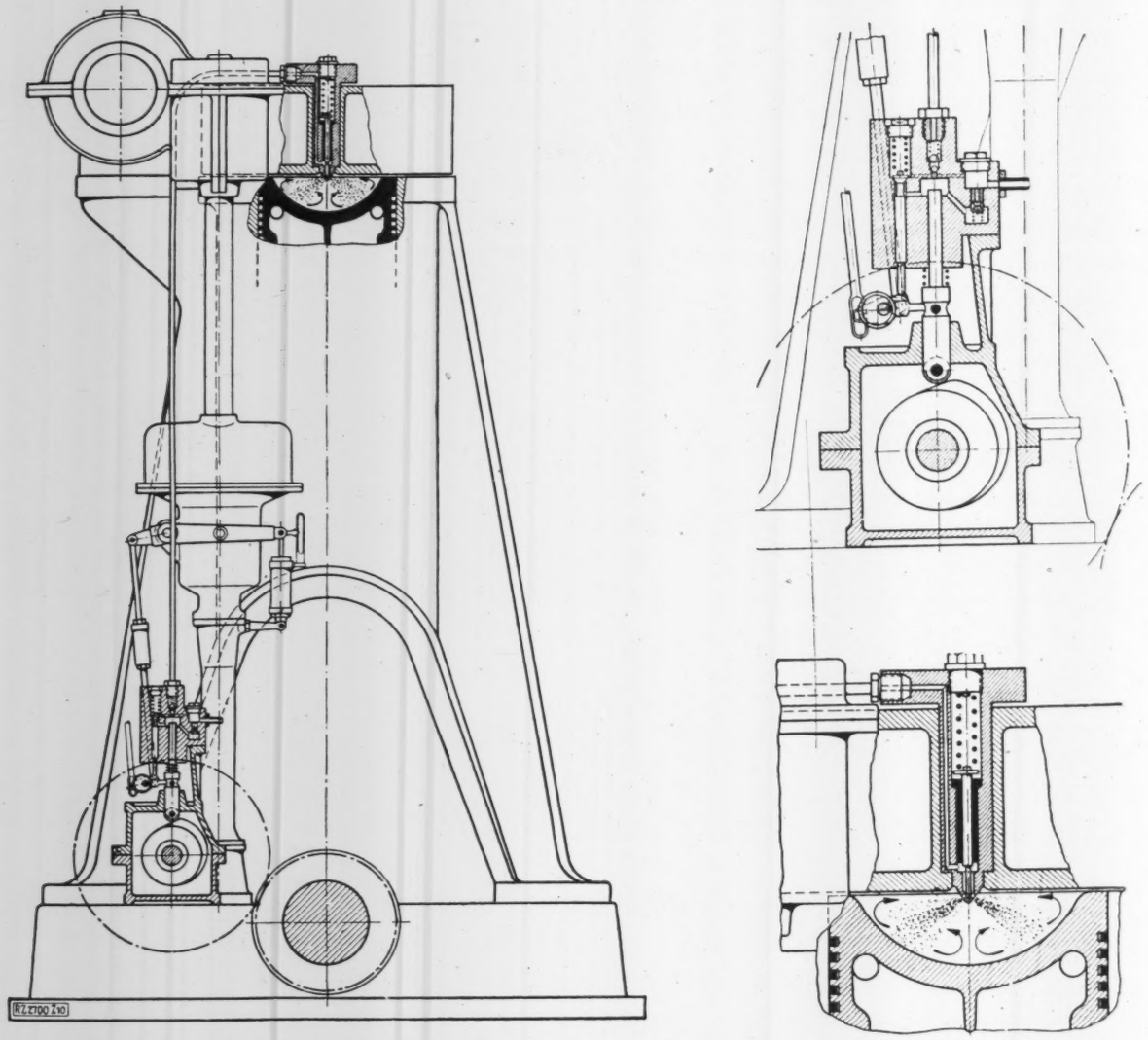

FIG. 1 LEFT: CYLINDER OF LINKE-HOFMANN COMPRESSORLESS DIESEL ENGINE SHOWING INJECTION DEVICE—RIGHT: FUEL-INJECTION PUMP (ABOVE) AND FUEL-INJECTION NOZZLE (BELOW)

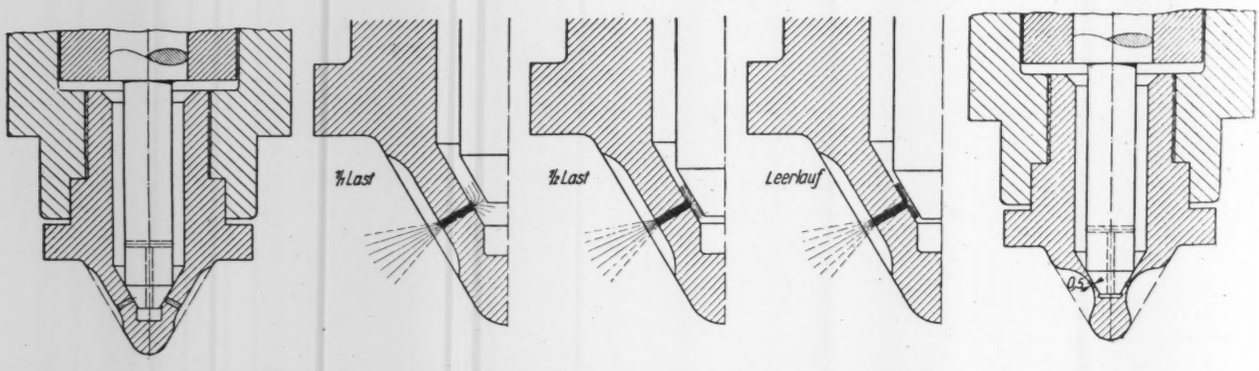

FIG. 2 EXTREME LEFT: GENERAL VIEW OF CLOSED NOZZLE—CENTER: THREE SKETCHES SHOWING NOZZLES WITH NEEDLE LIFTS AT FULL LOAD, HALF-LOAD, AND NO LOAD—EXTREME RIGHT: EXPERIMENTAL NOZZLE WITH THIN ORIFICES

The setting being complete for the development of the well, the 20-in. casing was pulled slowly, a few inches at a time, and water pumped by air lift from the well. As water was pumped sand flowed freely under the 20-in. casing and thence out of the well, and the gravel between the outer and inner casing settled. Pumping continued moderately until the water cleared. The clearing of the water indicated that the cavity formed by the removal of sand had filled with gravel and that the velocity of the water at the surface bounding the deposited gravel was so low that the sand would not carry through the voids. With clear water flowing, the 20-in. casing was raised a few more inches, thus increasing the velocity of water, and again a heavy flow of sand occurred. In order to keep the sand and gravel thoroughly agitated and the gravel forced back into the cavity made by the developing process, the well was alternately pumped and "back-blown." To back-blow the well the discharge valve was closed. The escape for air through the eduction pipe being thus shut off, the air, after forcing water out of the eduction pipe into the ground, passed through the strainer opening and bubbled up through the gravel, causing it to "boil." The back-blowing action also kept the gravel from arching in the casing, and the "boiling" or rising and falling of the gravel had the effect of forcing the gravel away from the well strainer. The valve upon the discharge pipe was opened after each 2- to 15-min. period of back-blowing. The pressure in the well, thus suddenly reduced to nearly zero from a pressure equal to the full head of water in the ground, caused an inrush of water at high velocity and a heavy flow of sand with it. The well was again pumped after back-blowing until the water cleared.

The process of pumping, "back-blowing," raising the 20-in. casing, and feeding gravel enough to keep the upper gravel surface a few feet above the end of the 20-in. casing, was continued intermittently until this casing had been entirely withdrawn. The space between the 12½-in. casing and the wall of the 30-in. hole was then filled with gravel to the ground surface. Alternate pumping and back-blowing was continued until the inflow of sand became small.

The unusual feature about this work is that from 500 to 800 gal. of water per min. is developed from a single well sunk in sand too fine to furnish such a flow from wells constructed by the usual methods. (Wynkoop Kiersted, Consulting Engr., Kansas City, Mo. in *Water Works*, vol. 66, no. 8, Aug., 1927, pp. 325–326, 2 figs., *d*)

ENGINEERING MATERIALS

Porous Concrete

THERE are two principles which have been utilized in the production of porous concrete. The first depends upon the generation of a gas during the process of setting, brought about by a chemical reaction resulting from the action of certain ingredients in the cement in combination with water upon certain added materials, such as certain metals in a fine state of subdivision and carbides of a type which undergo a slow decomposition in contact with water, e.g., aluminum carbide.

The second principle involves the use of a substance which is solid at a low temperature but liquefies with the rise of temperature, allowing the cement to form an outer coating while in the solid state, and of such a nature that when it assumes the liquid phase it enters into chemical combination with cements. Ice answers these requirements. Hence the product obtained by the application of this principle has been termed "ice concrete," whereas the one obtained by the process first described is spoken of as "gas concrete." A process patented in England consists of the addition to the cement of a mixture of so-called "slate-lime" and powdered metals such as aluminum, zinc, or magnesium, which generates gas from the resultant mixture on the addition of water. Slate-lime is an intimate finely divided mixture of calcined slate and lime, as, for instance, 50 per cent by weight of each, or 60 per cent by weight of lime and 40 per cent by weight of calcined slate. The amount of powdered metal is generally less than 1 per cent. It is claimed that the material manufactured according to this process has a high degree of porosity and that the pores are fully separated from one another by means of partition walls. Therefore air cannot circulate through the material. The material has considerable insulating power, which makes it very suitable for use in the construction of the exterior walls of buildings, and can be conveniently manufactured in the form of bricks or slabs.

"Ice concrete" has an advantage over "gas concrete" in that the form can be shaped in the course of manufacture, whereas the latter can be cut into desired form only after it has hardened. Because of the lightness of porous concrete and the small amounts of material required to produce a large bulk, it may prove attractive in the production of certain types of building materials where low cost is a prime factor. Being composed of inorganic materials it is not liable to decay, and may be classed as a fire retardant. (Herman E. Wennstrom, Univeral Trade Press Syndicate, in *Pit and Quarry*, vol. 14, no. 9, Aug. 3, 1927, pp. 45–46, *d*)

The Corrosion-Resistant Aluminum Product "Alclad"

THIS article describes a product newly developed at the Research Laboratories of the Aluminum Alloy Co. of America, and among other things discusses the question of the relative corrosion resistance of various aluminum alloys. The studies made there have led to the conclusion that commercially pure aluminum and at least one alloy containing about 1.25 per cent manganese are immune from intergranular penetration by corrosion. In contrast, the strong alloys in which the high strength and hardness are obtained by a heat treatment involving the precipitation of certain of the constituents, such as $CuAl_2$ and Mg_2Si, are more likely to suffer this type of attack, although not all do so to the same extent.

"Alclad" is essentially a composite material consisting of a strong aluminum alloy between layers of aluminum, although the actual method of its manufacture is not described. From data presented in the paper it would appear that this particular product is capable of considerable resistance to corrosion. (E. H. Dix, Jr., Metallurgist of the Research Bureau, Aluminum Co. of America, in a paper read before the Committee of Materials for Aircraft of the National Advisory Committee for Aeronautics at the Annual Aircraft Conference, Langley Field, Va., May 24, 1927; published in *Technical Notes, National Advisory Committee for Aeronautics*, no. 259, August, 1927, 13 pp., 3 sheets of illustrations)

FUELS AND FIRING (See also Marine Engineering: Pulverized Fuel for Marine Purposes)

A German Coke-Oven-Gas Scheme

GERMAN colliery interests propose to displace town gas works by a system of distributing coke-oven gas through high-pressure mains. At the recent meeting of the German Gas Association a paper was contributed by Herr Müller, of Hamburg, dealing with the technical and financial aspects of the scheme. From the map attached to the original paper it would appear that it is proposed to cover an area comprising over 60,000 square miles and extending as far as Hamburg on the north, Berlin and Dresden on the east, Stuttgart and Munich on the south, and Cologne and Frankfort on the west, with principal mains leading from the Ruhr coal fields.

From the technical point of view the most important difficulty appears to lie in the difference in the heating value of the gas proposed to be distributed and that now being supplied, the other problems, such as purification, handling of naphthalene, compression, etc., not being very difficult. (German gas works are now generally supplying gas at from 472 to 506 B.t.u., whereas the coke-oven supply is contemplated at about 530 B.t.u.)

The following figures are cited in pounds sterling on the financial side. The cost of the mains is estimated at £16,500,000, which at 10 per cent for interest and amortization would represent 7.5 d. (15 cents) per 1000 cu. ft. on the estimated consumption, to which must be added charges for compression, purification, storage, and transmission. On its own showing the potential profits, even taking into consideration certain side lines, such as the sale of gas coal, will be small for a number of years. But if the scheme materializes the coal syndicate will practically get a monopoly in fuel supply.

It is mentioned in this connection that in Great Britain in spite of the continuous threat and intermittent realization of trouble in

recent years in the coal fields, gas plants actually took for distribution in 1925 over 30 per cent more of coke-oven gas than in 1922. If peace in the coal fields continues, the figures are bound to increase, and especially as coke-oven owners are now more ready to guarantee supplies in accordance with the requirements of the British Gas Regulation Act. (From Current Topics in *The Gas World*, vol. 87, no. 2245, Aug. 13, 1927, pp. 137–138, *g*)

The Microstructure of New Zealand Lignites

For American mechanical engineers this article is more interesting from the point of view of the description of methods used than of results achieved. At the present time there are two methods in general use for studying the microstructure of coal. The older of these is the sectioning method; the younger, the method of etching. Sections of a coal may be made either by grinding it without any preliminary softening or by cutting it after it has been softened by the action of chemicals. The sections reproduced in this article were made by the latter method as far as the softening part of the process is concerned. But then instead of dehydrating and imbedding the coal in a nitrocellulose, the softened coal was transferred direct from phenol to paraffin and cut in paraffin.

The etching method is simply an extension and modification of the one used in investigating metals. In this case a slice of coal is cut, ground, and polished on one side. It is then etched in a boiling mixture of sulphuric and chromic acids for a time, depending upon the nature of coal. The various constituent vegetable elements in the coal are differently attacked by the oxidizing bath, and as a rule the etched coal shows very clear evidence of its origin, even such fine details as bordered pits becoming quite distinct.

Theoretically, either method is applicable to all kinds of coal; practically, neither is so applicable, at least in the hands of the average worker. Some hard coals are extremely difficult to section, while some lignites are so readily attacked by even moderately active etching fluids that the resulting surface is too coarse to be of value. Here it is that the two methods help one another out.

The rest of the article deals with the actual microstructure of the lignites and is illustrated by a number of photographs. (W. P. Evans, Ph.D., in *New Zealand Journal of Science and Technology*, vol. 9, no. 1, May, 1927, pp. 11–21, 16 figs., *eA*)

The Present Position of Low-Temperature Carbonization

The primary object of low-temperature carbonization in England [which is the country the author is dealing with] appears to be the production of a solid smokeless fuel suitable for use in the ordinary domestic grate or cooking range, and in the smaller industrial furnaces, as this would abate the smoke nuisance.

To achieve this object the coke produced must be in a suitable lump form strong enough to stand transport, easily ignitible, and reasonably free from ash. Such a fuel can be produced from suitable coal in retorts in which it lies quiescent during carbonization, such as the Parker retorts, or where it is only moved intermittently, as in the Fuel Research Station retorts. Any turning over, or considerable movement during carbonization, tends to form an undesirable amount of small coke. Experience at the Fuel Research Station indicates that any medium or strongly caking coal can be used, or a blend of weakly and strongly caking coals.

A process such as that outlined above produces a considerable amount of rich gas, with a calorific value in the neighborhood of 1000 B.t.u. per cu. ft. and full value for this can only be obtained if it be used for town gas—in other words, if disposed of through a gas company. In such a case it should be possible to credit the process with 3d to 4d (6 to 8 cents) a therm for the gas produced, whereas if the gas were used directly for heating the retorts, or under boilers, or for any other purpose where the high calorific value was of no particular advantage, the cash value of the gas would only be 1d or 2d (2 to 4 cents) a therm. For this reason it would appear that, generally, the proper place for carbonizing coal when the coke is to be used for domestic purposes is at a gas works. This has the further advantage that a market for the coke is also available on the spot, with a selling agency in existence.

For these reasons the government asked Sir David Milne Watson, the governor of the Gas Light and Coke Company, to go into the whole matter, and to say:

(*a*) Whether, in his opinion, any of these processes had reached such a point of development that it was worth while for his company to continue the experimental development on a large scale; (*b*) if so, whether he considered the selected process or processes sufficiently promising to justify his company in taking the entire risk of this development; and (*c*) if not, whether he would submit a scheme, after discussion, whereby the government would be asked to bear a part of the risk involved.

The result of his report was that a subsidiary company (Fuel Production, Ltd.) has been formed, the capital of which has been guaranteed under the Trades Facilities Act, to erect a plant at the Richmond Gas Works with a capacity of 100 tons a day, and of the general design developed at the Fuel Research Station. This plant will be worked by the Gas Light and Coke Company, and the experience gained should show in the course of two or three years whether such a scheme will pay or not. Arrangements have been made by which all the experience gained will be freely at the disposal of any company desirous of taking up the process.

Not all processes have to be worked in connection with the gas plant. For example, in the Maclaurin and Midland Coal Products processes a gas low in heating value is produced. In some cases the primary object of low-temperature carbonization may be recovery of the oil-producing tars from the coal to include the solid residue being used as an industrial fuel. In these cases the technical problem is in some respects simpler, as the coke need not be in lump form and the low ash content is not of great importance. It is thus possible to use a system in which the coal is turned over during carbonization with an increase of output by more rapid heating of the coal, and possibly use a coal of lower grade.

In other cases, again, the primary object may be to produce a comparatively high-grade solid fuel from a low-grade raw material, with the recovery of such gas and tar as may be feasible. Such processes have the greatest promise of success where large quantities of low-grade fuel exist naturally, and where they can be cheaply mined, as is the case with the brown coals in Germany, Canada, and Australia. They have also a definite but somewhat limited application in this country.

One great source of uncertainty in the financial outlook—and a financial profit is essential if any process is to be developed commercially—is the still unknown value of the tar. The tar is different both from high-temperature tar and from natural oils. Its properties have not yet been fully investigated, and their study forms the subject of most interesting research which is being actively pursued in several quarters, private and official, from various aspects. There is no doubt that these tars will yield fuel oil and motor spirit, but the best methods of treatment are not yet fully worked out. They will probably yield lubricating oils, and certainly various chemical products of use in the manufacture of disinfectants, preservative paints, and probably dyes and fine chemicals.

The general conclusion which may be drawn from the article is that the success of the various process of low-temperature carbonization will largely depend on the degree to which they can combine with other industries and also insure the proper utilization of all the products whether solid, liquid, or gaseous. The author concludes that it is unfortunately still a fact that no process has yet proved that it can make a profit. He hopes that this statement will no longer be true in the not too distant future. (Maj. E. O. Henrici in *Chemistry and Industry*, the Journal of the Society of Chemical Industry, vol. 46, no. 32, Aug. 12, 1927, pp. 721–723, and an editorial entitled Research, on p. 720, *g*)

INTERNAL-COMBUSTION ENGINEERING (See also Marine Engineering: Power Plant and Propelling System of the Hapag Liners; Motor-Car Engineering: A Diesel Tractor)

Recent Suggestions in Diesel-Engine Construction

Translation of a serial article in a German publication, *Schiffbau*, June 2 and 16 and July 7, 1926, parts of which have been abstracted in Mechanical Engineering under the title of New Trends in Diesel-Engine Design, vol. 48, nos. 8 and 9, Aug. and Sept., 1926, pp. 949 and 1053–1054. (F. Ernst Bielefeld in *Technical Memorandum, National Advisory Comm. for Aeronautics*, no. 425, Aug., 1927)

Dual Engines

MOTOR-CAR engines intended for developing as great a power as possible have been built as V-eights (which are twin-fours), straight-in-line eights, and twin-sixes. For airplane use 16-cylinder engines were built, and, as a matter of fact, vertical 12- and 16-cylinder engines are now built with an overall length no greater than that of 6- and 8-cylinder engines of the same cylinder bore. Quite lately on the Monza track 1500-cc. Fiat racing cars have appeared with 12 cylinders in two vertical rows of six, the two groups being set very close together and the two crankshafts being united by gearing. With a double piston displacement of 1500 cc. each cylinder is limited to 125 cc., which would give bore and stroke dimensions of approximately 50 × 63 mm. (1.98 × 2.48 in.). The weight of reciprocating parts is therefore exceedingly low, the inertia forces small, and such an engine ought to run at high crankshaft speed without notable vibration. Furthermore, such an engine is quite narrow and can easily be fitted under the ordinary hood.

In addition to the Fiat, Ettore Bugatti is said to have been at work for more than a year on a car with a dual engine in two groups of eight cylinders. Bugatti claims he took out patents in 1915 for dual-engine construction intended at that time for aviation work, and, as a matter of fact, exhibited in Paris dual engines of this type.

As a matter of historic interest it might be mentioned that the Dusenberg engine driven in 1920 by Milton on the Daytona Beach track at the then record speed of 155.3 m.p.h. had two engines side by side. It is not certain, however, that the two crankshafts were connected. (*Autocar*, vol. 59, no. 1658, Aug. 12, 1927, pp. 297–298, 4 figs., *d*)

Factors in the Design of Centrifugal-Type Injection Valves for Oil Engines

THIS research was undertaken at the Langley Memorial Aeronautical Laboratory, at Langley Field, Va., in connection with a general study of the application of the fuel-injection engine to aircraft. The purpose of the investigation was to determine the effect of four important factors in the design of a centrifugal-type automatic injection valve on the penetration, general shape, and distribution of oil sprays.

The general method employed was to record the development of single sprays by means of special high-speed photographic apparatus capable of taking 25 consecutive pictures of the moving spray at the rate of 4000 per sec. Investigations were made concerning the effects on spray characteristics of the helix angle of helical grooves, the ratio of the cross-sectional area of the orifice to that of the grooves, the ratio of orifice length to diameter, and the position of the seat. The sprays were injected at 6000, 8000 and 10,000 lb. per sq. in. pressure into air at atmospheric pressure and into nitrogen at 200, 400 and 600 lb. per sq. in. pressure. Orifice diameters from 0.012 to 0.040 in. were investigated.

This investigation has shown that although the application of centrifugal force to an oil spray does reduce the penetration, the spray may still maintain a relatively high degree of penetration into dense air. It has shown that examination of centrifugal sprays injected into the atmospheres may lead to incorrect conclusions as regards their characteristics when injected into dense air.

It was found that decreasing the pitch of helical grooves and thus increasing the centrifugal force applied to the spray increased the spray-cone angle considerably, although the percentage increase was much less in dense air than in the atmosphere. On the other hand, the spray penetration decreased with increase in the amount of centrifugal force applied. About twice as much spray volume per unit of oil was obtained with a high centrifugal spray as with a non-centrifugal spray. The spray cone angle increased, and the spray-volume-to-oil-volume ratio and spray penetration decreased with increase in the ratio of orifice area to groove area. Maximum spray penetration was obtained with a ratio of orifice length to diameter of about 1.5. Slightly greater penetration was obtained with the seat directly before the orifice. (W. F. Joachim and E. G. Beardsley in *Report No. 268, National Advisory Committee for Aeronautics*, 15 pp., 22 figs., *e*)

The Kinner 5-Cylinder Air-Cooled Engine

THIS is a five-cylinder four-cycle engine having a bore of 4.26 in. and a stroke of 5.24 in., and developing 100 hp. at 1800 r.p.m. at sea level. The weight of engine complete, ready to run, including propeller hub but no propeller, is 231 lb., while the maximum fuel consumption is 7 gal. per hr. The cylinders are cast of aluminum with integral cooling fins and two overhead valves. Each cylinder is a separate unit. The pistons are also of an aluminum alloy with two oil-wiper rings, one above and one below the wristpin. There is a master connecting rod with the other four pinned to it, making all connections adjustable by simply moving the pins. A good deal of attention was apparently paid in the design of this engine to make the parts accessible. (*Aviation*, vol. 23, no. 5, Aug. 1, 1927, pp. 251–252, 2 figs., *d*)

MACHINE PARTS AND DESIGN

The Efficiency, Strength, and Durability of Spur Gears

THE research with the first part of which this bulletin deals will be executed in five separate investigations, in connection with each one of which one or more bulletins will be published. For the purpose of convenient designation these different studies will be referred to here as Parts I, II, III, IV, and V.

Part I of the research, dealt with in the present bulletin, is a force-efficiency analysis of the Lewis-Webb gear-testing machine now so well and favorably known to mechanical engineers all over the world. To enhance the usefulness of the analysis in using this machine the tables which appear herein have been computed. These tables will, it is thought, make the efficiency expression presented quite as easy to use as the some what simpler, but less accurate, formula now employed in calculating the efficiency of the Lewis-Webb machine.

Part II of the research will consist of the design and analysis of a new type of gear-testing machine embodying the Webb closed-energy-circuit principle. This machine, which it is believed will be more sensitive and more accurate than the present machine, will enable the efficiency of a pair of spur gears to be determined not only when the friction at the bearings is neglected but also when it is included. The present machine is unfortunately inherently unsuited to meet the latter of these requirements.

Part III of the research will be an investigation, with the aid of this new machine, of the relation between the efficiency of spur gears and the following factors: 1, Pitch-line speed; 2, load per inch of width of face; 3, angular velocity ratio; 4, angle of pressure, 5, circular pitch; 6, lubrication.

Part IV of the research will be an investigation of the question of the dynamic load on the teeth of spur gears, that is to say, of the load on the teeth in excess of the static load; or in other words, the load on the teeth due to impact. This problem it is proposed to attack in two ways: first, by measuring directly the impact load; secondly, by measuring the angular acceleration of the gears which is caused by imperfect spacing and shaping of the teeth and which is proportional to the dynamic load. The instruments for making these measurements will constitute an important feature of the new testing machine.

The relation of this dynamic load to the static load having been determined for different pitch-line speeds, an attempt will then be made to correlate the total load to the dimensions of the teeth.

Part V of the research will be an experimental study of the problem of the durability of spur gears. Here an attempt will be made to discover for gears of different materials the relation between the rate of wear of the teeth and the economic life of the gears. Since, however, the relation between these two factors is a function of the pitch-line speed, the load, lubrication, the shape of the teeth, and the accuracy with which they are formed and space, it will be necessary to establish first the relation between each of these four factors and the rate of wear of the teeth. To accomplish this, therefore, will be the primary object of Part V of the research.

In developing the analysis with which the present bulletin is concerned, the author has been unable to adopt, because they seem to him untenable, two assumptions which hitherto have been made by users of the Lewis-Webb machine. These assumptions are:

1 To convert a scale reading into a friction tooth load, multiply

the former by the ratio of the length of the testing-machine beam to the radius of the pitch circle of the pinion.

2 The energy consumed in friction by the test gear and the test pinion is equal to the energy consumed in friction by the master pinion and master gear.

The reasons for rejecting these assumptions are fully explained in the original paper. In particular the reason for rejecting the second assumption grows out of the fact that such an assumption is evidently equivalent to the assumption that the efficiency of the test gear and test pinion is always higher than the efficiency of the master gear and master pinion when the test pinion and the master gear are drivers and the test gear and master pinion followers. This assumption may or may not be true, depending as it does upon variable stresses, as the author shows in the original paper. Some other features of the pneumatic type of machine are considered.

The first part of the investigation begins with the description of the machine to which the analysis applies and its operation, and from this proceeds to the force-efficiency analysis. This part begins with certain general assumptions, and thereafter the various force systems are considered. This part of the paper is not suitable for abstracting. (Wm. H. Rasche, Prof. of Mechanism, Virginia Polytechnic Institute, in *Bulletin No. 3 of the Engineering Experiment Station of the Virginia Polytechnic Institute*, June, 1927, 44 pp., 4 figs., *epA*)

MACHINE SHOP (See Mechanics: Pulley Diameter and Power Transmitted by Leather-Belt Drives)

MACHINE TOOLS (See Special Machinery: A Roll-Grinding Machine with Cambering Attachment)

MARINE ENGINEERING

Pulverized Fuel for Marine Purposes

The paper under consideration may be divided into two parts—one dealing with the general application of pulverized coal for marine purposes, and the other describing the Brand system and Brand radiant vertical water-tube boiler. The first part describes the Clarke-Chapman unit turbo-pulverizer and marine boiler with external combustion chambers. Among other things, reference is made to the so-called "distilled fuel," which is a carbon residue of low-temperature carbonization. Tests carried out last year by Clarke-Chapman & Co., Ltd., proved that the distilled residue obtained from the L & N process of low-temperature treatment (compare Mechanical Engineering, vol. 49, no. 5, May, 1927, p. 459) required from 12 to 15 per cent less power to grind than raw coal, and that ordinary gas coke demanded 10 per cent more power than coal. (It is not on record that the moisture contents were similar in the three fuels tried.) The same firm ascertained that by using hot air or waste fuel gas at about 260 deg. cent. entering the pulverizer as a conveying medium, the power required to grind coal is reduced by from 10 to 12 per cent. It should be pointed out that it is undesirable to use a temperature of over 150 deg. cent. except in the case of a unit pulverizer delivering the whole of its product direct to the furnace, as otherwise valuable volatile hydrocarbons will be driven off and wasted to atmosphere from the separator vents in the storage bins.

Since combustion space in the marine boiler is limited, the long-flame burners of the tubular or fish-tail type commonly used in land practice are unsatisfactory.

The burner must be capable of effecting complete combustion in a distance of about 6 ft., and since it is necessary for the particle to remain in the combustion zone for a certain period, it follows that to traverse a path of 30 ft., such as that often encountered in land boilers, the particles must follow a spiral path. The spiral will gradually straighten out as the influence of the energizer, i.e., the primary air, dies out. The velocity of projection is about 70 ft. per sec., and at completion of combustion 40 ft. per sec. (in the system with which the author is connected). The latter point is reached just before the mouth of the furnace proper. Tests with the Brand burner, using air heated to 150 deg. cent. and with coal containing 18 per cent of volatile hydrocarbons, gave a temperature of 1480 deg. cent. 15 in. from the burner mouth, combustion being complete at 5 ft.

If the primary or air accompanying the coal and used for projecting it into the furnace is cold, some time is required for its temperature to increase, since it is sluggish in absorbing radiant heat. The fuel dust absorbs radiant heat at a rapid rate, and parts with some of this by convection to the primary air, which lags behind the particles in temperature. In order, therefore, that particle, gas envelope, and air may all be near the ignition point on entering the furnace, it is desirable to preheat both primary and secondary air. No loss will ensue, since all volatiles and gases liberated from the fuel will enter the furnace. It is preferred if possible to obtain a preheat of 230 deg. cent. by using a heater placed in the path of the funnel gases. Again, just as turbulence has been found to play an important part in the combustion of oil in a Diesel engine, so it is a primary necessity for a short-flame powdered-fuel burner.

Tests are described on the use of pulverized fuel in Scotch boilers at sea, made by Clarke-Chapman & Co., Ltd., and a table is given showing comparative operating costs for a 40-day voyage. This table, however, is based not on actual facts but on certain assumptions. It does show a considerable saving in favor of pulverized coal as compared with either bulk coal or oil.

The second part of the paper is devoted to the Brand system of pulverized-fuel installation. In this case the fuel is dried and ground on shore and delivered to the bunkers by pipes. The method of burning this fuel is described in some detail. (Engr. Capt. J. C. Brand, R.A.N., in a paper read at the summer meeting of the Institution of Naval Architects, July 12, 1927; abstracted through *Shipbuilding and Shipping Board*, vol. 30, no. 3, July 21, 1927, pp. 67–70, 3 figs., *dc*)

Power Plant and Propelling System of the Hapag Liners

After giving a general history of the use of geared Diesel engines on shipboard, the author proceeds to the description of several motorships built for the Hapag (Hamburg America Line). In November, 1924, the Blohm & Voss Co. completed for the Hapag a twin-screw geared ship, the *Monte Sarmiento*, which was followed several months later by a sister ship, the *Monte Olivia*. In these ships the engine crankshaft is connected to the pinion in an unusual manner. The pinion is bored hollow and a quill-shaft attached to the free end. A torsion shaft rigidly connected to the crankshaft and about 23 ft. long runs through the pinion and quillshaft and is attached to the latter's end. Thus, a flexible connection is interposed between the engine and gear unit. The crankshaft is fitted with a very heavy flywheel, and a second one is fitted to the end of the pinion shaft. A short time later the same yard built the ship *Vriesland* in which the twin-screw arrangement was abandoned and replaced by single-screw propulsion. In this case the propelling machinery consists of a pair of ten-cylinder engines geared to a single propeller in exactly the same way as above. The propelling power transmitted through the low-speed gear is 4000 b.hp. in the motorship *Vulcan* commissioned in July, 1924, and the hydraulic clutch designed by Dr. Föttinger is installed. The same type of drive is applied to at least two other ships.

The new transatlantic ships for the Hamburg America Co. are novel in character in that they will have four Diesels of 12,200 collective b.hp., which will propel them at a speed of $16\frac{1}{2}$ knots. The engines are double-acting two-cycle units operating at 230 r.p.m., connected in pairs through gearing to the two propellers which operate at 110 r.p.m. normal speed. The engines are of M.A.N. type, but will be constructed by the yards building the ships, one by Blohm & Voss, Hamburg, the other by the Bremer Vulkan, Vegesack. Each engine has six cylinders of 19.5 in. diameter and 23.5 in. piston stroke. It is claimed that with this arrangement any danger of vibration of the ship's hull will be excluded, especially as there are four engines and the impulse from each piston stroke is only small. The height of the engines is small, so that decks can be extended over the engine room. The weight of the fast-running double-acting two-cycle engines per horsepower is said to be decidedly less than that of any other type.

The ships, which will be very similar to the steam-driven *Cleve-*

land class of the Hapag, will be named *St. Louis* and *Milwaukee*, respectively. The main dimensions of the vessels will be 540 ft. by 72 ft. by 36½ ft., and on a draft of 28 ft. they will carry 10,000 tons deadweight. (*Motorship*, vol. 12, no. 8, Aug., 1927, pp. 611–612, *d*)

MEASURING INSTRUMENTS

A Gas-Analysis Instrument Based on Sound-Velocity Measurement

THE instrument described in the paper here abstracted is based on a principle which has not hitherto been utilized in the design of gas-analysis instruments. The general idea is as follows: A quartz crystal is maintained in vibration piezoelectrically and stationary waves are set up in the gas between the flat surface of the crystal and a movable reflector. The position of the nodes is recognized by the reaction on the quartz crystal resulting in an increase of the current in the maintaining circuit. In this way the distance from node to node is measured. Since the velocity of sound in air is about 332 meters per second, and, for example, in carbon dioxide about 259 meters per second, it is assumed that if the velocity of sound in a mixture of carbon dioxide and air can be measured with sufficient accuracy, it should afford a method of analyzing the gaseous mixture. Such a physical measurement has the advantage that it does not involve the absorption of one constituent idea of the mixture and thus alter the position. It is not plain, however, that it is to be preferred to the simple direct chemical method for ordinary routine tests, but is put forward as a supplementary method for use in special cases. The apparatus is described in detail and its working explained. A table is appended showing the value of the velocity of sound in different gases at 0 deg. cent. References on piezoelectricity are also given.

In the discussion which followed, D. J. Blaikey told of an acoustic method of utilizing the principle of the stationary wave which was used by him and Prof. Geo. Forbes in an experimental apparatus designed for the detection of small quantities of firedamp or other gases in air. This apparatus is briefly described. Other references to similar apparatus are given in the author's reply to the discussion. (Ezer Griffiths, Physics Dept., National Physical Laboratory, in *Proceedings of the Physical Society of London*, vol. 39, no. 4, June 15, 1927, original paper, pp. 300–303, and one page of figures; discussion on pp. 303–304, *d*)

MECHANICS

Pulley Diameter and Power Transmitted by Leather-Belt Drives

AFTER explaining why the pulley diameter affects the power transmitted, the author presents data covering a range of drives with capacities from 5 hp. up to 1500 hp. After plotting these data a curve was drawn which placed nearly all the crosses which represented failures below and the circles representing satisfactory drives above. Oddly enough this curve [given in the original article] proved to be a straight line when plotted on logarithmic paper. A similar curve was plotted from successful and unsuccessful drives using flexible idlers. This second curve was 25 per cent lower than the curve on open drives and likewise a straight line when plotted on logarithmic paper. The increased effectiveness of the smaller pulley with flexible idlers was due to the great wrap of the belt on the pulley resulting from using the idler. For more ready reference two tables were compiled, one showing pulley diameters for horsepower ratings, and the other minimum diameters recommended for use with leather belts.

Among other things, the article discusses friction burning resulting from insufficient contact area. Friction burning is caused by the belt stretching, which reduces the pressure between the belt and pulley surface to a point where the small area in contact can no longer adhere, and excessive slipping is the consequence. The friction created by such slippage soon burns the belt's surface.

TABLE 1 PULLEY DIAMETERS FOR HORSEPOWER RATINGS

Horsepower	Minimum diam., in.	Horsepower	Minimum diam., in.
10	6	100	18
20	8	150	21
30	10	200	24
40	11	250	27
50	13	300	30
75	16	..	..

NOTE: The normal ratings are based on the use of pulleys no smaller in diameter than those given in the second and fourth columns above. Where smaller-diameter pulleys are to be used, complete operating data and a description of the drive should be submitted to the engineering department of the belt manufacturer, who will recommend the size and thickness of belt suited to the particular installation.

TABLE 2 MINIMUM DIAMETERS OF PULLEYS RECOMMENDED FOR USE WITH LEATHER BELTS

Linear velocity of belt in feet per minute			1000	2000	3000 and up
			Pulley diameter, in.		
Width	Ply	Weight Thickness, in.			
Up to 8 in.	Single	(*a*) Chrome 5/32	2	2½	3
		(*a*) Light 1/8	2	2½	3
		(*a*) Medium 6/32	3	3½	4
		(*a*) Heavy 3/16	4	5	6
Up to 12 in.	Double	Chrome 5/16	6	7	8
		(*a*) Light 1/4	4	5	6
		(*a*) Medium 5/16	8	10	12
		(*a*) Heavy 3/8	10	13	14
Up to 24 in.	Triple	Chrome 1/2	18	24	36
		(*a*) Heavy 9/16	24	30	36

(*a*) Oak-tanned leather belts.

This condition is first indicated by a glazed appearance, and in many cases causes actual charring of the leather, especially if such a condition is permitted to continue for any length of time. Burned belts have lost many of their necessary physical qualities, particularly elasticity, and it is impossible to restore them to good condition. A slipping belt with a good surface (coefficient over 0.5) practically always identifies itself by a squeal, but if the surface is glazed or oily it may slip quietly and be noticeable only by the heat of the pulley face. (Roy C. Moore, Ch. Engr. of Chas. A. Schieren Co., New York, in *Industrial Engineer*, vol. 85, no. 8, Aug., 1927, pp. 357–359, 4 figs., *p*)

MOTOR-CAR ENGINEERING (See also Internal-Combustion Engineering: Dual Engines)

A Diesel Tractor

DESCRIPTION of a caterpillar tractor equipped with an Atlas-Imperial oil engine. This was fitted on a gasoline-tractor frame with practically no mechanical changes except an extension on the frame which permits moving the radiator forward about 10 in.

Especial attention has been paid to the protection of the engine from the abrasive dust which is normally encountered in road service. The rocker arms, valve tappets, and spray valves have been entirely enclosed, and Purolator oil filters have been adopted to protect the oil supply. As in other models of Atlas-Imperial engines, a Protectomotor air filter is also used to prevent the entrance of dust with the intake air.

Developing 75 hp. at 650 r.p.m., with a bore of 6½ in. and a stroke of 8½ in., the engine operates with unusual freedom from vibration. According to the present operator it is possible to balance a pencil on the cylinder heads or rocker-arm brackets at speeds up to 900 r.p.m. Aside from the protective features mentioned above, the manufacturer's standard design practice is followed, including common-rail fuel pressure system, mechanically operated spray valves, force-feed lubrication, etc.

The first tests of this tractor have been carried out in earth-moving operations at the so-called "San Francisco bottle-neck," where especially designed scrapers of 15 yd. capacity are being used. Previous to using the Diesel caterpillar it was necessary to use two gasoline tractors for holding on to the load, but the ability of the oil engine to give a sustained "pull" during the loading of these scrapers has made it necessary to use only one of the Diesel tractors. (*Oil Engine Power*, vol. 5, no. 8, Aug., 1927, pp. 528–529, 2 figs., *d*)

POWER-PLANT ENGINEERING (See also Marine Engineering: Pulverized Fuel for Marine Purposes; Mechanics: Pulley Diameter and Power Transmitted by Leather-Belt Drives; Testing and Measurements: Hydrostatic Tests for Permissible Boiler Working Pressure)

Large Turbo-Generator Development

A SYMPOSIUM on this subject was recently presented before the Engineers' Society of Western Pennsylvania by three speakers, representing respectively each of the three builders of large

turbo-generators, namely, The American Brown Boveri Electric Corporation, The General Electric Company, and the Westinghouse Electric & Manufacturing Company. Because of lack of space only the salient points of this symposium can be noted here.

All three speakers called attention to the very rapid development in size of generators within the last three years, and explained the factors which made it possible.

L. T. Peck, of The American Brown Boveri Electric Corp., called attention to the fact that, with respect to the generator, one of the previously recognized limitations, that of ventilation, has been greatly raised, if not completely removed. The mechanical bracing of stator coils is believed to be adequate to prevent damage to the windings under short-circuiting, regardless of size, and, as the inherent characteristics are under the control of the designer with assurance of stability, the limit as to size for a given speed is largely dependent upon the success of the metallurgist in producing a material which will enable one to increase the peripheral speed of the rotor beyond that which is now considered the maximum safe speed.

At the present time, he said, there is under construction a turbo-generator of 88,250 kva. to operate at 1800 r.p.m., and it is of interest to note that the diameter of the rotor will be 58 in., with a resultant peripheral speed of about 455 ft. per sec.

Taking into consideration the safety factor represented by testing at 25 per cent overspeed, Mr. Peck was inclined to believe that, with existing materials, a diameter of 60 in. at 1800 r.p.m., corresponding to 470 ft. per sec., is the limit of good practice, and therefore the present capacity limit at this speed, so far as diameter is concerned. If this is correct, the length of rotor will determine the ultimate capacity of a machine of 1800 r.p.m. The generator of 88,250 kva. will have a length between bearings of approximately 21 ft. 6 in., which is well within safe limits, but no prediction can be safely made as to the maximum permissible length of rotor for a given diameter, as there are too many factors to be considered. Furthermore, such a prediction would place a limit on ultimate capacity, and in the light of progress made in the past few years this might be both undesirable and misleading.

Mr. Peck also stated that where the operating economy is of first importance and ample space is available the multi-cylinder single-shaft unit with no restrictions as to length (with attendant limitation of stages and leaving area) can be constructed for outputs equal to those of the largest generators yet designed and gives exceptionally good performance, not only in these sizes but when used with relatively small generators. (Pp. 193–197.)

Walter B. Spellmire, of the General Electric Co., told of the large units installed by that organization. He stated that recent research development has resulted in five large stations operating today at pressures around 600 lb. and two with 1200 lb. initial pressure at the turbine throttle. It seems reasonable to suppose that 600 lb. may become a common pressure and that 1200 lb. or some higher pressure will be used both in new stations and through the use of the so-called reducing-valve type of turbine to prolong the economic life of old stations.

The development of high-pressure apparatus can also reasonably be expected to result in the use of reducing-valve turbines as a means of producing the process steam required in many manufacturing industries. (Pp. 198–210, 10 figs.)

F. D. Newbury, of the Westinghouse Electric & Manufacturing Co., gave additional facts regarding the history of the development of the large turbo-generators, with particular reference to recent developments. It would appear that in three years from 1923 to 1926 the maximum unit at 1800 r.p.m. has more than doubled in size. Furthermore, recent developments have made it possible to design four-pole generators of such large size that generators of lower speed need scarcely be considered.

He next told about the various ventilating systems used in the last twenty years and the experimental work conducted by C. J. Fechheimer at the Westinghouse plant, which latter has resulted in a system in which the advantages of the simple radial system of ventilation can be obtained with a core of any length.

Another important factor in the rapid increase in maximum ratings that has occurred during the past three or four years has been the improved rotor materials and constructions, as well as new methods of winding insulation. (Pp. 211–218.)

In the discussion which followed, one of the speakers, W. B. Spellmire, told about the research on the flow of gases carried out at the General Electric Co. by Mr. Wirt in connection with wind tunnels. In the past it has been customary to assume that when a certain ventilating scheme was put into effect—on a turbine rotor, for example—the air must flow in the direction in which it had been planned to flow. Investigation by Mr. Wirt showed that many previous assumptions were in error. To illustrate Mr. Wirt's investigation, the inside of the exhaust end of a steam-turbine casing was considered. It was painted with a mixture of oil and lampblack—a mixture which would not dry out quickly. Fluid was then passed through the casing and the whirls and eddies actually taking place were recorded on the lampblack mixture and impressions taken from this record by means of plaster of paris. The negative thus obtained was studied.

Results of similar experiments showed that a gaseous fluid passing through a pipe with a sharp right-angle bend met with less resistance than a fluid passing, under the same pressure and density, through the same size of pipe with a curved bend, this being contrary to all assumptions. However, if vanes were placed in the curved right-angle bend, then the resistance was tremendously reduced. The resistance to the flow in the three cases illustrated was in the order of magnitude of 5, 6, and 1. (*Proceedings of the Engineers' Society of Western Pennsylvania*, vol. 43, no. 4, May, 1927, pp. 193–218, discussion pp. 218–219. The page numbers for each paper of the symposium are given at the end of each abstract. *hg*)

Power-Plant Failures

AN EDITORIAL based on reports issued by the British Engine, Boiler, and Electrical Insurance Co., Ltd. Among other things, this report describes failures of two engines dating from 1860. While the parts, such as shaft, in one case, and crank, in another, broke, the report says, it was only after very long service, involving some hundreds of millions of revolutions.

Several cases are reported of damage due to the failure of cast iron when exposed to superheated steam. In one case an unusual noise was heard in a cylinder, and on opening it up fragments of cast iron were found inside, the origin of which was not discovered till some months later, after additional trouble and damage on two occasions. Ultimately it was found that the fragments responsible had come from a cast-iron disk valve in the superheater. These valves had been examined on the occasion of the first accident, but superficially, being merely felt by hand instead of being opened up. In another case, during the periodical examination of a 1500-kw. impulse steam turbine, the cast-iron casing was found to be seriously cracked. In this instance the steam temperature occasionally rose to 600 deg., though the designed limit was 550 deg. The crack started at a groove which had been machined for registration purposes in the head of the casing and went through to the steam belt.

Several cases are recorded of blade strips. In some instances the damage was discovered only on opening up the turbine for its periodical examination, the station staff having had no suspicion that anything was wrong. In another instance the sole indication observed was that the gage between the third and fourth groups of some reaction blading was showing a higher pressure than the normal. On opening out this turbine, three blades were found broken out of the eighth group, and the stator blading of the ninth group was damaged. No trace of the broken blades could be found, a condition which it may be said is by no means unprecedented when reaction blading strips; the broken blades are then rolled and beaten up into small fragments, which find their way into the condenser. As it was not convenient to replace the broken blading immediately, the damaged ring was merely cut out and the turbine set to work again pending a more convenient season.

Two instances are reported in which blading had been injured in riveting up the shrouding into place. The blades were of bronze, and had their ends tanged to receive the shrouding which was secured by riveting down the tangs. The metal had in this instance been so damaged by this operation that the tangs parted and the shrouding came off. In another case blades broke owing to the fact that during erection they had not been properly tightened into the slot machined in the wheel to receive them. Some builders,

it may be stated, will not permit work of this kind to be done by piece.

One interesting case of excessive wear is reported, the inlet edges of the blades of a two-row velocity compounded wheel being worn down by no less than $^1/_4$ in.

That speeds are still tending to increase is indicated by the fact that one of the failures concerned a turbine of 850 hp. rating which ran at 5000 r.p.m., while another 500-b.hp. machine had a running speed of 6000 r.p.m. The highest speed recorded in the report relates, however, to a small simple impulse machine designed to develop 20 b.hp. at a speed of 19,200 r.p.m. This was coupled with 10-to-1 gearing to a fan which had to be kept running day and night for months on end and under abruptly changing loads. Under these trying conditions it had been found necessary to reline the bearings four times during the year, and ultimately there was a breakage both of buckets and gear teeth. It may be noted that a very similar trouble with a DeLaval turbine of 450 b.hp. was described a few years since in the *Bulletin de la Société de l'Industrie Minérale*. In this case the turbine ran at 7500 r.p.m. With the types of compressor originally adopted there were constant breakdowns, the wheel and gears having to be replaced five times in six years. An examination of the wheel teeth led to the conclusion that they had been subjected to cold-hammering, and a study of the compressor then made, showed that under certain conditions there were great cyclical variations in the load. The compressor was accordingly replaced by another make free from this defect, and there was no further trouble.

In another part of the report, L. W. Schuster gives a very complete discussion of the strength of crane hooks, as calculated by the mathematical theory of elasticity. As is now well known, the Andrews-Pearson formula suffers from three defects. In the first place it is inconsistent with the known result that Poisson's ratio does not appear in discussions of plane stress, unless the form studied be "multiply connected;" in the second place the formula is very complicated, and finally it provides no indication of the existence of radial stresses. Correct solutions of the problem of the crane hook were, it appears, worked out on the continent nearly 20 years ago, and the same solution was arrived at independently in *Engineering* of Sept. 5, 1913, p. 307. A very complete and general discussion of this and allied problems was given by Professor Inglis in a paper read before the Institute of Naval Architects in 1922, and it is this treatment which has been adopted by Mr. Schuster. It is, however, perhaps open to question whether the ordinary elastic theory suffices to fix the strength of hooks. All solid sections subject to bending prove stronger than indicated by this theory. In other cases, however, such as punching- or slotting-machine frames, which are often of box or I-beam section, the radial stresses may, as was pointed out in the above-mentioned issue of *Engineering*, be more important than the tangential. Quite recently, again, Prof. W. Hovgaard has shown that it is the existence of these radial stresses which renders pipe bends much more flexible than the ordinary theory would indicate. (*Engineering*, vol. 124, no. 3213, Aug. 12, 1927, pp. 208–210, *pg*)

PUMPS

Cost of Operating Motor-Driven Centrifugal Pumps

AN ARTICLE based on data of pumping operations at McKeesport, Pa. In this case the power is purchased from the Duquesne Light Co., and it is stated that from the time the plant was started (1925) until the present date, there has been only one interruption of service and that was due to a short-circuit which lasted about forty minutes. Under this contract the cost of power has averaged ten and seven-tenths mills per kilowatt-hour, ranging from 60 mills for the first 200 kw-hr. down to as low as 7 mills per kw-hr., and in terms of the demand charge of $1.50 per month per kw. for the first 100 kw. of demand and $1.00 per month per kw. for each kilowatt in excess of 100. These bills then are subject to a prompt-payment discount of 5 mills per kw-hr. for all energy billed at 60 mills per kw-hr., 2 mills per kw-hr. for all energy billed at 27 mills per kw-hr., 1 mill per kw-hr. for all energy billed at $13^1/_2$ mills per kw-hr., and then there is a variable discount for power factor better than 75 per cent. At 100 per cent power factor this discount amounts to 8.819 per cent.

The motors used are synchronous; the pumps for the reservoir are two-stage series pumps, and those for the standpipe are of the four-stage single-suction type. There are duplicate pumps for each installation and 500-hp. motors are installed for each pump for each service. Some difficulty was experienced in the first month of operation due to the inability to get the power-factor meter properly registering, and due to the fact that the valves on the discharge lines were bypass gate valves; it was found advisable to replace them with hydraulically operated gate valves so that the motors could build up to synchronous speed before the valves were opened and the full load thrown on them with minimum amount of labor. This necessitated the closing and opening of each discharge gate valve in starting up each pumping unit, which was done by man power, but by the installation of hydraulically operated valves the operating force will be reduced by two men per day, the third-shift man being retained in the plant for general-utility purposes.

The article enumerates in detail the various items of cost and presents actual figures, both in tables and in the text. A summary is reproduced herewith.

SUMMARY OF COST PER THOUSAND GALLONS OF WATER PUMPED

Interest on investment	$0.0014
Depreciation charges	0.0005
Man-power cost	0.0055
Energy cost	0.0165
Heat, telephone, and electric light	0.0003
Oil, waste, and incidental expenses	0.0001
	$0.0243

(Leo Hudson and A. J. Richards, the former of Hudson & Myron, Cons. Engrs., Pittsburgh, Pa., and the latter Supt. of the Dept. of Public Safety, McKeesport, Pa., in a paper before the Central State Section of the American Water Works Association; abstracted through *Water Works*, vol. 66, no. 8, Aug., 1927, pp. 339–341, *p*)

SAFETY ENGINEERING (See Power-Plant Engineering: Power-Plant Failures)

SPECIAL MACHINERY

A Roll-Grinding Machine with Cambering Attachment

DESCRIPTION of a machine made by the Churchill Machine Tool Co., Broadheath, England, fitted with mechanisms for producing cambered rolls. The unique feature of the cambering device (Fig. 3) is the straight-edge cambering bar.

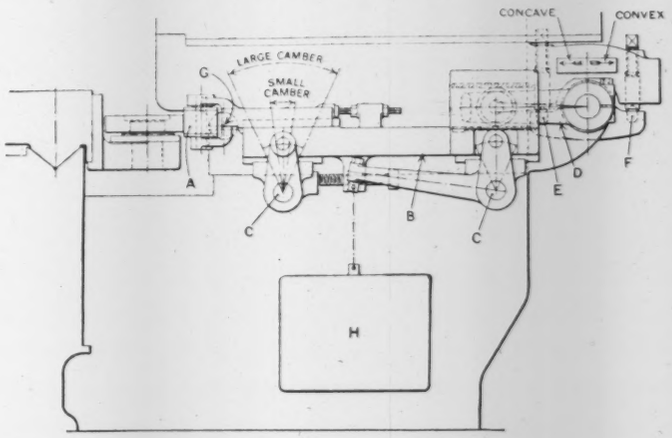

FIG. 3 CAMBERING ATTACHMENT OF THE CHURCHILL ROLL-GRINDING MACHINE

Bearing on the edge of the cambering bar is a roller *A*, carried by a bracket that can be adjusted in position on the horizontal bar *B*. This bar forms the upper member of a link motion, the links being supported by the pins *C*. The rear link is provided with an arm, the end of which supports the weight *H*, this weight tending always to keep the roller in contact with the camber bar.

The camber-bar pivot shown in dotted lines is carried by the

work table, and it is clear that as the work traverses to and fro, the roller and its carrier, together with the link motion, will be moved in a horizontal direction, the upper ends of the links traversing small arcs, as shown at the left-hand link.

The extent of the movement of these links is shown by the notes "large camber," "small camber," on the drawing, the total angular movement being governed by the inclination of the camber bar.

The machine is suitable for grinding rolls up to 40 in. in diameter and not exceeding 10 ft. in length. (*Machinery* (London), vol. 30, no. 772, July 28, 1927, pp. 518–519, 3 figs., *d*)

SPECIAL PROCESSES

New Forge Shop at the Willys-Overland Plant

One outstanding feature of the new forge shop at the Willys-Overland plant is the provision made for straight-line production. Another is the excellent facilities for the handling of materials. Both have brought about tremendous reductions in costs. In addition, a train of other vastly important advantages has resulted, many of which will be appreciated in full measure only as time goes on.

The former storage yard along the creek bank has been replaced by three yards directly beside the shear sheds. Each is served by an overhead traveling crane. Carloads of steel are spotted under these cranes and the material is placed directly in storage. From this point, as ordered for forging, the bars are put on a roller conveyor leading in to the shears. The maximum travel from cars to storage is 160 ft. and the average is 80 ft. Distances from storage to shears are similarly 160 ft. maximum and 80 ft. average, or only 17 per cent of what they formerly were.

The bars are cut to correct lengths, and the pieces are then loaded into large skids mounted on legs to allow them to be handled by Clark Truclifts. Order slips show to which hammers they are to be delivered.

The bars remain in the skids until required for the heating furnaces. Then they are heated, forged under the hammer, trimmed in the presses, in some cases put through an upsetting operation, and loaded, while still hot, into skids for transportation to the next process, which usually is heat-treating. Flashings, while still hot, are likewise placed in skid boxes of a special dump type, which, when full, are carried to the scrap bins and dumped.

All moving of materials from the shearing operation to the heat-treating process, and then through successive other steps which are carried on in the forge shop—such as straightening, inspection, etc. —is done by means of skid boxes handled by the gasoline lift trucks. This type of equipment was adopted because of its superiority for the particular type of work called for by the forge shop, where operations are often continuous during three daily shifts, and the trucks must give 24-hour service. They run at high speed, turn on a very small radius, are easy to manipulate, and cost little to operate.

When the forgings are ready for machining they are delivered by the gasoline lift trucks to trailers outside of the forge shops. The forgings are dumped into these trailers by means of a hoist, and a tractor then takes them to the machine shop, as before.

Each of the five lift trucks works in a definite portion of the forge shop and the driver learns the best method of serving his division. All boxes of parts during internal transportation in the shop are ordered moved by small slips attached to them, bearing the order number, part name, quantity, department delivering, and department to receive the material. No driver is allowed to move anything without one of these move slips. He collects the slip in each case, and at the end of the day turns them all in with his time card. He is paid on a piece-work basis for the quantities handled, each item having its own standard rate.

The new forge shop has been in operation too short a time to compile detailed costs on all branches of its operation. But some figures have been worked up which are suitable for general comparison with corresponding former costs, and are fairly representative of each individual type of handling.

The former way of handling materials to and from storage was by means of locomotive cranes. With the new overhead-traveling crane method the cost has been cut 39 per cent.

It now costs slightly more than $0.05 per ton to handle steel bars and forgings by the lift-truck method.

Taking the general average cost of transportation in the new shop as fairly representative of trucking costs between forging and heat-treating operations, we can make a direct comparison with former data. Previously, by the tractor and trailer method, the cost was $0.1430 per ton. Now the average cost is $0.0514, a saving of $0.0916 per ton, or 64 per cent.

Scrap bins for flashings are now located almost in the same position as formerly, but new methods are used to cut down the cost of handling this waste material. Previously it was thrown on the floor beside each press, loaded into trailers, sorted by hand, and thrown into bins. Then it was loaded on cars by locomotive crane and magnet and delivered to the baler.

Now the flashings are put directly from the presses into Phora Iron Works special dump skid boxes, are carried by lift trucks to the scrap bins, and dumped. As the materials have been kept separated, no sorting is required at the bins.

For changing dies on the hammers and presses, two Automatic electric high-lift elevating trucks are used. They run directly up to the machines, eliminating the use of cranes for the purpose. Dies are carried by this means from storage to hammers and presses, and back again when the machines are put on a different kind of work.

The elevating truck also carries dies between the forge shop, the die-making and the die-repairing shops, which are nearby. In addition, it facilitates furnace repairs. All this latter work is done in the basement of the forge shop, where supplies of necessary materials are stored. Furnace sections are carried by overhead traveling cranes to a hatchway and lowered on the platform of the truck, which then carries them to the repair room. The truck can reach the lower level because the ground slopes at the forge shop and the driveway at one end is at basement level. Storage space shows a similar favorable comparison. Due to the greater facility with which the new shop can turn out forgings, work in process has been cut down one-third for the same output; and due to the convenience with which material can be gotten from railroad cars into the shops, storage space has been reduced from about 45,000 sq. ft. to 25,000 sq. ft., a reduction of 45 per cent. At the same time, the idea of considerably increased production has been kept in mind, so the relative figures are even more striking.

Incidentally, No. 2 power house, adjoining the old forge shop, was combined with No. 1, modern equipment was installed, and $8000 to $10,000 per month is now being saved because of the increased efficiency. (John N. Willys, president of the Willys-Overland Co., in *Manufacturing Industries*, vol. 14, nos. 2 and 3, August and September, 1927, pp. 91–94 and 197–202, 14 figs., *d*)

Centrifugally Made Concrete Pipe

Description of the method of manufacture of pipe used in the Laguna Beach water-pipe line and in the main supply line for the City of Riverside, Cal., now under construction.

The manufacturing process is comparatively simple. The pipe is made in steel forms. After the material has been distributed evenly inside of the form and smoothed down into the reinforcing cages by hand, the cylinder is spun for four or five minutes. This compresses the material against the side walls of the container, while the surplus water, etc. remain upon the inner surface of the pipe. After five to eight minutes of rotation the machine is stopped and this surplus of water or other material is brushed out. After cleaning the interior surface the pipe is again spun, the second operation lasting about three minutes. After the second spin the aggregate is so hard that it is impossible to make an indentation on the interior surface with a thumb or finger. The second spin also imparts a glaze to the interior surface which is said to give this type of pipe a very low friction coefficient when in use.

The pipe is made both with and without reinforcement. The reinforcing material is No. 8 cold-drawn steel wire and is placed in the pipe in the form of cages which are made by a specially designed machine.

In making tests upon this type of pipe, the hydrostatic test has proved to be the best. It has been found that standard-run pipe, 14 to 16 days old, which was designed for 125-ft. heads, withstood 250 ft. head. One section that was made for only 50 ft. head was brought up to 195 ft. head before it failed. While the Laguna Beach pipe line was being laid, tests were conducted

daily at the manufacturing plant, and practically all of the pipe tested withstood twice the pressure for which it was designed. It was the general custom, however, to test the pipe to 150 per cent of the line pressure, and in every case this was attained without any seepage whatsoever. The engineer's report on this job showed a joint of 27-in. pipe withstanding a pressure of 110 lb. per sq. in. without seepage, indicating a unit tensile strength in excess of 400 lb.

External top-load tests were also conducted. Several sections, however, were brought to a point of failure, one being a 27-in.-diameter section with a wall thickness of $2^5/_8$ in., designed for a 50-ft. head, which was 23 days old. The specified test upon this pipe was 26,400 lb., and was brought to failure at 33,800 lb., when the pipe showed slight cracks at each end in the bottom only. The spring lines were not affected. This particular section was then placed in a hydrostatic testing machine and subjected to an internal pressure of $32^1/_2$ lb. for 20 min. without showing any signs of seepage. The process is substantially the same as the Hume process which was described in the way it is applied in South Africa in MECHANICAL ENGINEERING, vol. 43, no. 7, July, 1921, p. 475. (Graydon Oliver in *Modern Irrigation*, vol. 3, no. 5, May, 1927, pp. 11–13, and 24, illustrated, *d*)

TESTING AND MEASUREMENTS (See also Machine Parts and Design: The Efficiency, Strength, and Durability of Spur Gears; Fuels and Firing: The Microstructure of New Zealand Lignites)

Hydrostatic Tests for Permissible Boiler Working Pressure

THE high-pressure boiler installed at the Edgar station of the Boston Edison Co. was originally intended to be used at 1200 lb. pressure. So successful, however, was its operation that it was decided to increase the working pressure, and the Massachusetts Board of Boiler Rules was called upon to approve such an extension to 1400 lb. To determine the allowable working pressure in the boiler headers, the Board desired hydrostatic tests to be made. The tests as made at the shops of the Babcock & Wilcox Co. followed the methods proposed by a special sub-committee of the A.S.M.E. Boiler Code Committee (see MECHANICAL ENGINEERING, vol. 49, no. 8, Aug., 1927, p. 929).

The inclined upper deck section, the vertical lower deck section, and a junction box were submitted to the hydrostatic tests. Each section was subjected to repeated applications of progressively higher hydrostatic pressure. In each case total deformation was measured with the pressure on, and after each such observation the pressure was released and measurements were made to determine permanent deformation, if any. The pressure was increased by equal increments up to 3900 lb. per sq. in. At most of the stations the proportional limit was obviously exceeded by this pressure, but at some of the stronger sections the stresses produced were still below the proportional limit.

For each station or measuring point, two curves were plotted with hydrostatic pressure as ordinates, one showing the total deformities under pressure, and the other showing the permanent deformation when the pressure was removed. Fig. 4 is a sample of the curves obtained. A straight line is drawn through the average of the points that lie approximately in a straight line on the curve of total deformation. The proportional limit occurs at the hydrostatic pressure where the curve through the points deviates from this straight line. It will be seen that this point is checked closely by the point at which appreciable permanent deformation starts. Small permanent deformations that occur prior to the point of proportional limit, caused by irregularities in the material, may be disregraded. For each header the average hydrostatic pressure corresponding to the proportional limit of similar points at the weakest sections of the head was determined.

The tensile strength and the proportional limit of the material were determined by tensile test of coupons taken from the header. Several specimens of the material were taken from the ends of the header before it was machined. Additional test coupons were taken after the hydrostatic tests had been performed. The average of the results of these physical tests is given in a table in the original article.

The results of these tests indicate that the inclined headers for the Edgar boilers are good for a maximum allowable working pressure of 1466 lb. per sq. in., that the vertical headers are good for a maximum allowable working pressure of 1766 lb. per sq. in., and the junction box for 1675 lb. per sq. in.

As a result of these tests, the Massachusetts Board of Boiler

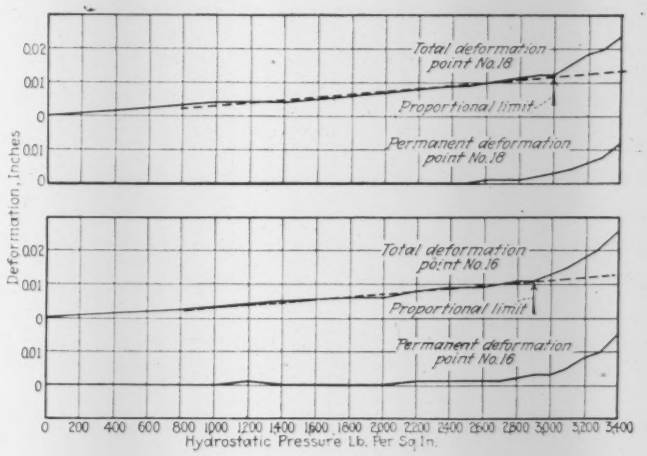

FIG. 4 STRESS-STRAIN CURVES PLOTTED FROM RESULTS OF HYDROSTATIC TESTS

Rules has passed the Edgar boilers, allowing a maximum working pressure of 1400 lb. per sq. in. Pressure parts other than the headers were found to be the limiting factor. It is expected that these boilers will be put in operation within the next few months. (*Power*, vol. 66, no. 9, Aug. 30, 1927, pp. 324–325, 2 figs., *ed*)

VARIA

Sir Charles Parsons on Inventions

AT THE recent meeting of the British Association, the new president, Sir James Henderson, made an address on inventions in which he deprecated wasted effort in this field and among other things claimed that in certain ways the American patent system was superior to the British.

Sir Charles Parsons, supporting the vote of thanks, said that, judging from the number of inventions that came before him, there seemed to be a superfluity of good or bad seed. There were really two sides to the question that had been raised by the President as to the need for more publication of previous unsuccessful efforts, because such publication might actually be a discouragement to an inventor. When he [Sir Charles] started on the steam turbine, had he known that some 100 patents for turbines had been taken out during the previous half-century, he might not have gone on with the work himself. When he was at the Board of Inventions during the war, suggestions came in at the rate of 2400 per week, but only a fraction of 1 per cent were of any use, and they were usually not new. As to the difference in the position of the inventor in America and in England, Sir Charles said he did not think the conditions in America were so favorable to the inventor as they were in England. For instance, it was very difficult to enforce patent rights in America. A vast amount of money would be involved and unless the patent was a powerful one, it was hopeless to start a patent action either against an individual or against the Government. That had been his own personal experience. A patentee was dealt with far more fairly and favorably in England than in America; that again had been his personal experience. That was a strange fact, for as we looked upon America as a progressive country we should expect the inventor to be encouraged. (*The Engineer*, vol. 144, no. 3739, September 9, 1927, pp. 273–274, *g*)

The Latest Scientific Prospecting Methods

A BRIEF presentation of some prospecting methods, particularly those used in South Africa. The following methods are described.

Gravity Method. In this the torsion balance is principally used. It was first constructed by the Hungarian professor, Eötvös, but

the type now used was improved by Professor Schweydar. The torsion balance gives a means of determining how gravity changes with change in position on the air surface. The instrument consists mainly of a light beam equally weighted at both ends and suspended in the middle by means of a thin platinum-iridium wire of constant torsional resistance. The new type has a double balance with two independent beams and a photographically registering device. If this instrument is placed in the neighborhood of a particularly dense mass it will register no change if the mass lies in a line parallel to the beam, or immediately beneath it. But if the mass lies anywhere else, the beam tends to turn with its nearer end toward the mass, as far as the torsion resistance of the wire allows. This permits locating the mass in question. The method seems to be particularly applicable in the investigation of salt domes, anticlinal folds, faults, and volcanic and mineral deposits on a large scale. Coal, which is always lighter than the surrounding rock, can be located when there is the question of a steeply inclined or of an abruptly terminating occurrence.

Electromagnetic Method. This method rests on the fact that the direction and density of an electric current passing through the earth depend upon two factors: (*a*) frequency; (*b*) differences in the electrical conductivity of the underground masses.

The fact is utilized by sending an artificially produced electric current through an area to be examined and measuring its direction and density. The results obtained are evaluated, i.e., on the basis of these results and of the actual geological conditions, and conclusions are drawn as to the position and size of the parts of the formation under investigation. The most essential point, then, is the difference in conductivity exhibited by the various parts of the formation. The greater these differences are, the surer will the conclusions be.

Whether the electrodes through which the current is sent into the earth are to be separated by shorter or longer intervals, and whether the distance of the electrodes from the area shall be greater or smaller—these are questions wholly dependent on the actual conditions; no general rules can be laid down for them, as indeed all geophysical methods cannot be guided by hard-and-fast rules in respect of their application, but must be adjusted to meet the exigencies of local conditions.

As regards its application, it should be observed that good conductors are lead, zinc, copper, manganese, nickel, and cobalt ores (but not all), tinstone, pyrites, etc., and in addition, some coals (anthracite), salt lyes, graphite, and especially, for instance, water in dry regions.

Bad conductors, apart from a few minerals (zinc blende, chromium ores, sulphur), are mineral oil, dry brown coal, glimmer, asbestos, talc, etc.

Before each experiment careful conductivity tests should be made. Here again the greater the difference and the sharper the transitions, so much the better will the results be.

Magnetic-Intensity Method. The theoretical basis of the magnetic method is as follows: Distinctions are made between diamagnetic, paramagnetic, and ferromagnetic rocks. Diamagnetic rocks break up the magnetic lines of force running through the earth and so cause magnetic minima. Paramagnetism or magnetic susceptibility is the property of concentrating the lines of force of earth magnetism, that is, of producing magnetic maxima. Ferromagnetism is a further increase in magnetic susceptibility.

In the present case the vertical intensity of the magnetic force is measured, as well as its deviations which are caused by varying magnetic properties of the different parts of the underground formation. By this means conclusions can be drawn as to the nature of the underground formations. As regards its practical application, the discovery of ferromagnetic and paramagnetic deposits naturally comes into the question. But ever smaller differences in susceptibility can be detected with the above-described instrument. In favorable cases the magnetic method can be used alone; in the main, however, it forms a valuable supplement to the other method. (R. Ibach in *Mining and Industrial Magazine*, vol. 4, no. 9, June 29, 1927, pp. 445–447, 4 figs., *d*. It may be that the article from which this abstract is made does not describe all the methods now available and, for example, omits all references to location of underground deposits by measuring variations in propagation of sound, as done, for example, in America by an instrument called the "osiso," and by variations in the conductivity of radio waves.—EDITOR)

WELDING

Welding Novelties at the Shipping, Engineering, and Machinery Exhibition in London

AMONG the many devices shown at the exhibition held at Olympia, London, in September, 1927, the following two dealing with welding attracted particular notice: The Anglo-Swedish Electric Welding Co., Ltd., showed four standard sizes of self-regulating welding sets. In these the generators may be driven by electric motors or oil engines, and portable or stationary sets are supplied. A noteworthy feature of the sets is that they have no switchboard, the makers having found that for welding purposes switchgear and instruments are unnecessary. Although the sets are designed mainly for use with the Swedish-Electric Welding Co.'s own electrodes, they may be used with other electrodes. An example of one of the engine-driven sets is shown in the original article, the engine being of the Aster four-cylinder type. The generator can be regulated to give from 40 to 250 amperes, and is capable of supplying 300 amperes intermittently. The set is suitable for welding with iron and steel electrodes from 2 mm. to 7 mm. diameter, and with brass electrodes up to 5 mm. diameter. The generator is totally enclosed, and all the regulation is done by a single handwheel, mounted in front of a graduated scale. The company showed a new motor-generator set, capable of being regulated from 10 to 125 amperes and of giving 150 amperes for short periods. It is suitable for use with iron and steel electrodes ranging from the smallest size up to 4 mm. It may also be used intermittently with 5-mm.-diameter electrodes.

The other novelty shown was exhibited by the Alloy Welding Processes, Ltd., of 14 Church St., Islington. Hitherto it has been usual when welding with three-phase alternating current to draw the supply from one phase of the system. Equipment here described permits using the three phases at the arc. Two of the phases are connected to a twin electrode consisting of two rods insulated from one another, while the third phase is connected to the work. This gives a rotating arc between the electrodes and the work, and only one phase gives zero current at any instant. Apart from the fact that the system balances the load on the mains, which is advantage from the central-station engineer's point of view, it has been found that the open-circuit voltage can be considerably reduced, and that the power factor is greatly improved. It is said to be possible to strike and maintain the arc with an open circuit pressure as low as 35, while the voltage across the arc is only 25. Both from the points of view of safety and of the rate at which the metal can be deposited, the system is claimed to offer considerable advantages, because one operator can deposit twice as much metal in a given time as compared with an operator using a single electrode. It is stated, in fact, that one man can do the work that is normally done by two. The three-phase arc is also said to maintain a practically constant temperature, and to keep the gases in the space between the electrodes and the work in a state of permanent ionization, thus increasing the conductivity of the arc and reducing the required voltage. An illustration in the original article shows the external appearance of one of these three-phase arc-welding equipment with the front of the case opened. In order to prevent an arc from being maintained between the rods forming the twin electrode a switch is provided, either on the electrode holder or the welding screen, for the purpose of extinguishing this arc. This switch is connected to a three-pole contactor, which, when opened, makes all the welding cables dead. It is said that the operator soon becomes accustomed to this device, and that he opened the switch at the same instant as he draws the electrodes away from the work. (*The Engineer*, vol. 144, no. 3739, September 9, 1927, pp. 277 and 278, *d*)

CLASSIFICATION OF ARTICLES

Articles appearing in the Survey are classified as *c* comparative; *d* descriptive; *e* experimental; *g* general; *h* historical; *m* mathematical; *p* practical; *s* statistical; *t* theoretical. Articles of especial merit are rated *A* by the reviewer. Opinions expressed are those of the reviewer, not of the Society.

Revisions and Addenda to Boiler Construction Code

IT IS THE policy of the Boiler Code Committee to receive and consider as promptly as possible any desired revision in the Rules in its Codes. Any suggestions for revisions or modifications that are approved by the Committee will be recommended for addenda to the Code, to be included later on in the proper place in the Code.

During the past two years the Boiler Code Committee has received and acted upon a number of suggested revisions which have been approved for publication as addenda to the Code. These are published below, with the corresponding paragraph numbers to identify their locations in the various sections of the Code, and are submitted for criticisms and comment thereon from any one interested therein. Discussions should be mailed to C. W. Obert, Secretary to the Boiler Code Committee, 29 West 39th St., New York, N. Y., in order that they may be presented to the Boiler Code Committee for consideration.

After 30 days have elapsed following this publication, which will afford full opportunity for such criticism and comment upon the revisions as approved by the Committee, it is the intention of the Committee to present the modified rules as finally agreed upon to the Council of the Society for approval as an addition to the Boiler Construction Code. Upon approval by the Council, the revisions will be published in the form of addenda data sheets, distinctly colored pink, and offered for general distribution to those interested, and included in the mailings to subscribers to the Boiler Code interpretation data sheets.

For the convenience of the reader in studying the revisions, all added matter appears in small capitals, and all deleted matter in smaller type.

Revisions and Addenda

PAR. P–23. REVISED:

P 23. *Thickness of Steam Piping.* In determining the thickness to be used for pipes at different pressures and for temperatures not exceeding 750 deg. fahr., for steel or iron pipe, and 406 deg. fahr., for brass and copper pipe, the following formulas are to be used:

For pipes having nominal diameters of from 1/4 in. to 5 in.,

$$P = \frac{2S}{D}(t - 0.065) - 125$$

For pipes of nominal diameter over 5 in., $P = \frac{2S}{D}(t - 0.1)$,

where

P = working pressure, lb. per sq. in.
t = thickness of wall of pipe, in.
D = actual outside diameter of pipe, in.
S = 12,000 LB. PER SQ. IN. FOR SEAMLESS MEDIUM CARBON STEEL PIPE
= 9000 lb. per sq. in. for seamless LOW CARBON steel pipe
= 7000 lb. per sq. in. for lap-welded steel pipe
= 5000 lb. per sq. in. for butt-welded steel pipe
= 5300 lb. per sq. in. for lap-welded wrought iron pipe
= 4500 lb. per sq. in. for butt-welded wrought iron pipe
= 4500 lb. per sq. in. for brass pipe
= 4000 lb. per sq. in. for copper pipe.

[Where] WHEN A pipe is [used] pierced with tube holes THE MAXIMUM ALLOWABLE stress in the ligaments may be taken as [the stress specified above for seamless] ONE-FIFTH THE MINIMUM TENSILE STRENGTH OF THE material AS SPECIFIED IN SECTION II OF THE CODE, provided the tube holes do not pierce the weld IN WELDED PIPE, and provided that the pressure shall not be greater than that allowed for the unpierced pipe.

PAR. P–186. REVISED:

P–186. *Welded Joints.* The ultimate strength of a joint which has been properly welded by the forging process, shall be taken as 35,000 lb. per sq. in., with steel plates having a range in tensile strength of 45,000 to 55,000 lb. per sq. in. Autogenous welding may be used in boilers in cases where the stress or load is carried by other construction which conforms to the requirements of the Code and where the safety of the structure is not dependent upon the strength of the weld. JOINTS BETWEEN THE DOORHOLE FLANGES OF FURNACE AND EXTERIOR SHEETS MAY BE BUTT OR LAPWELDED BY THE FUSION PROCESS PROVIDED THESE SHEETS ARE STAYED OR OTHERWISE SUPPORTED AROUND THE DOORHOLE OPENING AND PROVIDED THE DISTANCE FROM THE FLANGE TO THE SURROUNDING ROW OF STAYS OR OTHER SUPPORTS DOES NOT EXCEED THE PERMISSIBLE STAYBOLT PITCH AS PER PAR. P–199. IF SUCH JOINTS ARE LAPWELDED THE EXTERIOR SHEET FLANGE SHOULD PREFERABLY BE PLACED ON THE OUTSIDE OR NEXT TO THE DOOR OPENING AND THE FIREBOX SHEET FLANGE ON THE INTERIOR NEXT TO THE WATER. AUTOGENEOUS WELDED CONSTRUCTION MAY BE USED IN LIEU OF RIVETED JOINTS IN THE FIREBOXES OF INTERNALLY-FIRED BOILERS, PROVIDED THE WELDS ARE BETWEEN TWO ROWS OF STAYBOLTS, OR IN THE CASE OF FLAT SURFACES THE WELD IS NOT LESS THAN ONE-HALF OF A STAYBOLT PITCH FROM THE CORNER.

PAR. P–194. REVISED SECOND SECTION TO READ:

P–194. When a dome is located on the barrel of a locomotive-type boiler or on the shell of a horizontal-return tubular boiler, the diameter of the dome shall not exceed six-tenths the diameter of the shell or barrel of the boiler UNLESS THE PORTION OF THE BARREL OR SHELL UNDER THE DOME (THE NEUTRAL SHEET) IS STAYED TO THE HEAD OR SHELL OF THE DOME BY STAYS WHICH CONFORM IN SPACING AND SIZE TO THE REQUIREMENTS GIVEN IN PAR. P–199 and TABLE P 7. WITH SUCH STAYED CONSTRUCTION THE DIAMETER OF A DOME LOCATED ON THE BARREL OR SHELL OF A BOILER IS LIMITED TO EIGHT-TENTHS OF THE BARREL OR SHELL DIAMETER.

PAR. P–200. REVISED:

P–200. *Staybolts.* The ends of staybolts or stays screwed through plates shall extend beyond the plate not less than two threads when installed, after which they shall be riveted over or upset by an equivalent process without excessive scoring of the sheets; or they shall be fitted with threaded nuts through which the bolt or stay shall extend. The outside ends of solid staybolts 8 in. and less in length, IF OF UNIFORM DIAMETER THROUGHOUT THEIR LENGTH, shall be drilled with TELL-TALE [a] holes, at least 3/16 in. diameter, to a depth extending at least 1/2 in. beyond the inside of the plate[s, or] IF SUCH STAYBOLTS ARE REDUCED IN SECTION BETWEEN THEIR ENDS BELOW THEIR DIAMETER AT THE BOTTOM OF THREADS, THE TELL-TALE HOLES SHALL EXTEND AT LEAST 1/2 IN. BEYOND THE POINT WHERE THE REDUCTION IN SECTION COMMENCES. Hollow staybolts may be used IN LIEU OF SOLID STAYBOLTS WITH DRILLED ENDS. [On boilers having a grate area not exceeding 15 sq. ft., or the equivalent in gas or oil fired boilers, the drilling of staybolts is optional.] Solid staybolts over 8 in. long, and flexible staybolts of either the jointed or ball-and-socket type, need not be drilled. Staybolts used in water-legs of water-tube boilers shall be hollow or drilled at both ends, irrespective of their length. All staybolts not normal to the stayed surface shall have not less than three engaging threads of which at least one shall be a full thread.

PAR. P–216. REVISED:

P–216. Stays or braces shall be used in the tube sheets of a fire-tube boiler if the distance between the edges of the tube holes exceeds the maximum pitch of staybolts for the corresponding plate thickness and pressure given in Table P–6. That part of the tube sheet which comes between the tubes OR CYLINDRICAL FURNACE and the shell need not be stayed, if the greatest distance measured along a radial line from the inner surface of the shell to the center point of the tangent common to any two tube holes OR TUBE HOLE AND CYLINDRICAL FURNACE on the shell side of such holes does not exceed 1.5 times the maximum pitch of staybolts for the corresponding plate thickness and pressure given in Table P–6. The tube holes OR TUBE HOLE AND CYLINDRICAL FURNACE to which a common tangent may be drawn in applying this rule shall not be at a greater distance from edge to edge than the maximum pitch referred to.

PAR. P–218. REVISED:

P–218. When stays are required the portion of the heads below the tubes in a horizontal-return tubular boiler shall be supported by through stays with nuts inside and outside at the front head and

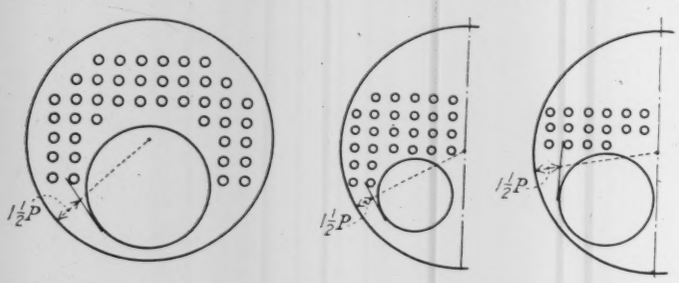

FIG. P-11A EXAMPLE OF STAYING OF HEADS ADJACENT TO CYLINDRICAL FURNACES

by attachments which distribute the stress at the rear head. Where a manhole opening is provided, IN THE HEAD BELOW THE TUBES OF A HORIZONTAL-RETURN TUBULAR BOILER, the flange of which is formed from the solid plate and turned inward to a depth of not less than three times the required thickness of the head, measured from the outside, the area to be stayed as indicated in Fig. P–11, may be reduced by 100 sq. in.

The distance in the clear between the bodies of the braces, or of the inside braces where more than two are used, shall not be less than 10 in. at any point.

PAR. P–249. REVISED:

P–249. *Tube Holes and Ends.* Tube holes shall be drilled full size from the solid plate, or they may be punched at least 1/2 in. smaller in diameter than full size, and then drilled, reamed or finished full size with a rotating cutter. TUBE HOLES MAY BE COUNTERBORED WHERE THE METAL IS THICKER THAN THAT REQUIRED TO GET A PROPER BEARING BY EXPANDING, SO AS TO FORM NARROW SEATS INTO WHICH THE TUBE ENDS CAN BE PROPERLY EXPANDED,

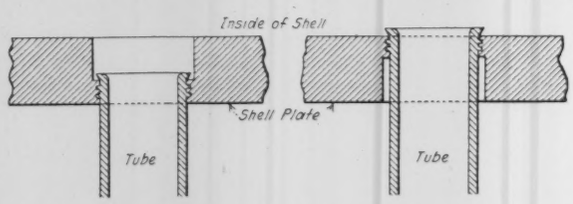

FIG. P-14A METHODS OF INSERTING TUBES IN THICK-WALLED DRUMS

PROVIDED THERE IS SPACE AVAILABLE TO PERMIT OF A PROPER AMOUNT OF FLARE OF THE TUBE END.

The sharp edges of tube holes shall be taken off on both sides of the plate with a file or other tool.

PAR. P–257. REVISED:

P–257. *Calking.* The calking edges of plates, butt straps and heads shall be beveled to an angle not sharper than 70 deg. to the plane of the plate, and as near thereto as practicable. Every portion of the unfinished surfaces of the calking edges of plates, butt straps and heads shall be planed, milled or chipped to a depth of not less than ONE-FOURTH OF THE THICKNESS OF THE PLATE, DOWN TO A MINIMUM OF 1/8 IN. Calking shall be done with a tool of such form that there is no danger of scoring or damaging the plate underneath the calking edge, or splitting the calked sheet.

PAR. P–268. REVISED:

P–268. *Threaded Openings.* All pipe threads shall conform to the American Pipe Thread Standard and all connections 1 in. pipe size or over shall have not less than the number of threads given in Table P–10. For smaller pipe connections there shall be at least four threads in the opening.

If the thickness of the material in the boiler is not sufficient to give such number of threads, the opening shall be reinforced by a pressed steel, cast steel, or bronze composition flange, or plate, so as to provide the required number of threads.

When the maximum allowable working pressure exceeds 100 lb. per sq. in. [a nozzle or saddle flange riveted to the boiler to receive a flanged fitting shall be used for all pipe openings] OUTLET CONNECTIONS over 3 in. pipe size SHALL NOT HAVE SCREWED JOINTS.

FLANGED FITTINGS SHALL BE USED RIVETED ON TO THE SHELL OR WITH A RAISED FLAT FACE ON THE BOILER SIDE CONNECTED DIRECTLY TO THE BOILER OR HEAD OF THE BOILER BY MEANS OF STUDS.

IF STUDS ARE USED THEY MUST BE NOT LESS THAN 3/4 IN. DIAMETER AND MUST HAVE NOT LESS THAN TEN THREADS PER INCH.

THE THICKNESS OF THE BOILER PLATE MUST BE NOT LESS THAN THE DIAMETER OF THE STUDS.

THE ALLOWABLE TENSILE STRESS ON THESE STUDS MUST NOT EXCEED THE STRESSES INDICATED BY THE BOLTED CONNECTIONS GIVEN IN TABLE A–6.

PAR. P–296. REVISED:

P–296. *Steam Gages.* Each boiler shall have a steam gage connected to the steam space or to the water column or its steam connection. The steam gage shall be connected to a syphon or equivalent device of sufficient capacity to keep the gage tube filled with water and so arranged that the gage cannot be shut off from the boiler except by a cock placed near the gage and provided with a tee or lever handle arranged to be parallel to the pipe in which it is located when the cock is open. Connections to gages WHICH ARE FILLED WITH WATER shall be of brass, copper or bronze composition. CONNECTIONS THAT ARE FILLED WITH STEAM SHALL, FOR PRESSURES OVER 250 LB. PER SQ. IN. AND TEMPERATURES IN EXCESS OF 406 DEG. FAHR., BE OF STEEL PIPE OR OF OTHER MATERIAL CAPABLE OF SAFELY WITHSTANDING THE TEMPERATURES CORRESPONDING TO THE MAXIMUM ALLOWABLE WORKING PRESSURE. WHERE STEEL OR WROUGHT IRON PIPE CONNECTIONS ARE USED THEY SHALL BE NOT LESS THAN 1 IN. PIPE SIZE.

Where the use of a long pipe becomes necessary, an exception may be made to the rule that the gage must be arranged so that it cannot be shut off except by a cock placed near the gage, and a shut-off valve or cock arranged so that it can be locked or sealed open may be used near the boiler. Such a pipe shall be of ample size and arranged so that it may be cleared by blowing out.

PAR. P–301. REVISED:

P–301. *Stop Valves.* Each steam-discharge outlet, except safety-valve and superheater connections, shall be fitted with a stop valve located as near the boiler as practicable. When such outlets are over 2-in. pipe size, the valve or valves used on the connection shall be of the out-side-screw-and-yoke rising-spindle type, AND THE WHEEL MAY BE CARRIED EITHER ON THE YOKE OR ATTACHED TO THE SPINDLE.

PAR. P–308. REVISED:

P–308. Each boiler shall have a bottom blow-off pipe, fitted with a valve or cock, in direct connection with the lowest water space practicable; the minimum size of pipe and fittings shall be 1 in., and the maximum size shall be 2 1/2 in., EXCEPT THAT FOR BOILERS 24 IN. OR LESS IN DIAMETER THE MINIMUM SIZE OF PIPE AND FITTINGS MAY BE 3/4 IN. Straight-run globe valves of the ordinary type as shown in Fig. P–19, or valves of such type that dams or pockets can exist for the collection of sediment, shall not be used on such connections. Return connections of the same size or larger than the size herein specified may be used, and to which the blow-off may be connected. In such case, the blow-off must be so located that the connection may be completely drained.

PAR. P–321. REVISED:

P–321. The water connections to the water column of a boiler, when practicable, shall be provided with a cross at each right-angle turn to facilitate cleaning. For steam pressures of 250 [200] lb. or less, the water connection, if pipe is used, shall be of brass. The water column shall be fitted with a drain cock or drain valve with a suitable connection to the ashpit, or other safe point of waste, and if the water connection thereto has a rising bend or pocket which cannot be drained by means of the water-column drain, an additional drain shall be placed on this connection in order that it may be blown off to clear any sediment from the pipe. The water-column blow-off pipe shall be at least 3/4-in. pipe size. For steam pressures over 250 [200] lb., the connections shall be of steel pipe or tubing, wrought-iron pipe or of other material capable of safely

withstanding the temperatures corresponding to the maximum allowable working pressure.

PAR. A–19. REVISED:

A–19. FIRE-ACTUATED fusible plugs, if used, shall be filled with tin with a melting point between 400 and 500 deg. fahr., and shall be renewed once each year. Where the boilers are to be operated at working pressures in excess of 225 lb. per sq. in. gage, the use of fusible plugs is not advisable.

PAR. A–20. REVISED:

A–20. The least diameter of fusible metal IN A FIRE-ACTUATED PLUG shall be not less than $^1/_2$ in., except for maximum allowable working pressures of over 175 lb. per sq. in. or when it is necessary to place a FIRE-ACTUATED fusible plug in a tube, in which case the least diameter of fusible metal shall be not less than $^3/_8$ in. (see Fig. A–10). If a FIRE-ACTUATED fusible plug is inserted in a tube, the tube wall shall be not less than 0.22 in. thick or sufficient to give four threads.

PAR. A–21. REVISE FIRST SECTION TO READ:

A–21. [Each boiler may have one or more] FIRE-ACTUATED fusible plugs, IF USED, SHALL BE located at the lowest permissible water level [as follows] FOR DIFFERENT TYPES OF BOILERS AS GIVEN BELOW: STEAM-ACTUATED PLUGS, IF USED, SHALL BE SO LOCATED THAT THEY WILL OPERATE WHEN THE WATER LEVEL IS AT THE POINT WHERE A FIRE-ACTUATED FUSIBLE PLUG WOULD BE LOCATED IF INSTALLED UNDER THESE RULES:

PAR. H–1*b*. REVISED:

H–1*b*. To steel-plate hot-water boilers not exceeding 60 in. in diameter OR WIDTH, or 160 lb. working pressure, or temperatures not exceeding 250 deg. fahr.

PAR. H–74. REVISED:

H–74. *Material for Base Metal.* The base metal composing the plates of autogenously welded steel-plate heating boilers shall be OF GOOD WELDABLE QUALITY AND SHALL BE MADE BY THE OPEN-HEARTH PROCESS, CONFORMING TO THE REQUIREMENTS OF THE SPECIFICATIONS FOR FORGE WELDING, PARS. U–110 TO U–125 OF SECTION VIII OF THE CODE OR TO THOSE FOR FLANGE AND FIREBOX CLASSES OF STEEL GIVEN IN PARS. S–5 TO S–17 OF SECTION II OF THE CODE [made by the open hearth process of soft and good weldable quality and shall conform to the following requirements:]

[Chemical Composition by Ladle Test]:

[Carbon by combustion test.....not over 0.15 per cent]
[Manganese.....not over 0.60 per cent]
[Phosphorus.....not over 0.05 per cent]
[Sulphur.....not over 0.05 per cent]

PARS. H–75, H–76, AND H–77—OMIT:

Insert Specification for Steel Plate of Flange Quality for Forge Welding, Pars. U–110 to U–125 of Section VIII of the Code.

TABLE H–4. REVISED:

TABLE H–4 MAXIMUM ALLOWABLE STRESSES FOR STAYBOLTS AND STAYS OR BRACES

Description of staybolts and stays or braces	Stresses, Lb. per Sq. In. For lengths between supports not exceeding 120 diameters.[1]	Stresses, Lb. per Sq. In. For lengths between supports exceeding 120 diameters.[1]
a Unwelded or flexible staybolts less than 20 diameters[1] long, screwed through plates with ends riveted over, or such staybolts welded in by the autogenous process...	7,500	....
b Hollow steel staybolts less than 20 diameters[1] long, screwed through plates with ends riveted over, or such staybolts welded in by the autogenous process...	8,000	....
c Unwelded stays or braces and unwelded portions of welded stays or braces.....	9,500	8,500
d Steel through stays or braces exceeding 1½ in. diameter[1].....	10,400	9,000
e Forge-welded portions of stays or braces..	6,000	6,000

[1] Diameters taken at body of stay or brace.

PAR. U–23. REVISED:

U–23. Pressure vessels shall not be fabricated by means of fusion welding under the rules given in Pars. U–67 to U–79, except:

a Air vessels, when the diameter does not exceed 20 in., the length does not exceed 3 times the diameter, and the working pressure does not exceed 100 lb. per sq. in.

b Other vessels, under these rules, in which the circumferential joints only may be welded, when the inside diameter does not exceed 48 in., or 72 in. when at least 75 per cent of the load on a flat head is supported by tubes or THROUGH stays EXTENDING FROM HEAD TO HEAD.

PAR. U–31. REVISED:

U–31. The longitudinal joints of a shell not more than 48 in. in diameter, WITH THE EXCEPTION GIVEN BELOW, may be of lap-riveted construction; but the maximum allowable working pressure of such construction shall not exceed 150 lb. per sq. in., nor 200 lb. per sq. in. for vessels less than 24 in. in diameter.

WHEN A VESSEL IS USED FOR A PURPOSE THAT MAKES IT NECESSARY TO PROVIDE IN ITS CONSTRUCTION FOR EXTRAORDINARY WEAR, CORROSION OR OTHER DETERIORATION IN SERVICE AND PLATES OF GREATER THICKNESS ARE USED THAN WOULD OTHERWISE BE REQUIRED, THE LONGITUDINAL JOINTS OF SHELLS EXCEEDING 48 IN. IN DIAMETER MAY BE LAP-RIVETED IF THE FOLLOWING CONDITIONS ARE MET:

THE OPERATING PRESSURE SHALL NOT EXCEED 50 LB. PER SQ. IN.

THE PLATE THICKNESS SHALL BE AT LEAST 1.8 TIMES THE REQUIRED PLATE THICKNESS.

TELL-TALE HOLES $^1/_8$ IN. TO $^1/_4$ IN. IN DIAMETER SHALL BE DRILLED TO A DEPTH OF AT LEAST 60 PER CENT OF THE REQUIRED PLATE THICKNESS IN THOSE SURFACES OPPOSITE THE SURFACES SUBJECTED TO WEAR OR OTHER DETERIORATION, WITH THE SPACING OF THE TELL-TALE HOLES NOT OVER 2 FT. APART.

PAR. U–53. REVISED:

U–53. All vessels for use with compressed air, 18 [16] in. in diameter, or over, and not exceeding 36 in. in diameter, shall have a handhole in the shell, or head, A MANHOLE OR AT LEAST TWO PLUGGED THREADED OPENINGS AT LEAST 2 IN. PIPE SIZE [or have a manhole].

All such vessels less than 18 [16] in. IN diameter SHALL BE PROVIDED WITH AT LEAST TWO HANDHOLES, OR TWO INSPECTION HOLES, PROPERLY LOCATED FOR INSPECTION, THE INSPECTION HOLES TO BE NOT LESS THAN $1^1/_2$ IN. PIPE SIZE, UNLESS THE VESSELS [may be constructed without a handhole, provided there are at least two pipe connections, or provided they] have REMOVABLE [bolted blank flanged] heads OR COVER PLATES.

PAR. U–59. REVISED:

U–59. All pipe threads shall conform to the American Pipe Thread Standard and all connections 1 in. pipe size or over shall have not less than the number of threads given in Table U–5. For smaller pipe connections there shall be at least four threads in the opening.

If the thickness of the material in the pressure vessel is not sufficient to give such number of threads, the opening shall be reinforced by a pressed steel, cast steel, or bronze composition flange or plate, riveted or brazed on, or a boss may be built up by an autogenous welding process for an opening not to exceed 2 in. pipe size, and for a pressure not to exceed 100 lb. per sq. in., so as to provide the required number of threads.

When the maximum allowable working pressure exceeds 125 lb. per sq. in. AND ALL PIPE OPENINGS [a connection attached to the pressure vessel to receive a flanged fitting shall be used for all pipe openings] over 3 in. pipe size SHALL BE PROVIDED WITH A FLANGED FITTING ADAPTED TO RECEIVE A PIPE FLANGE AND WHICH MAY BE ATTACHED TO THE PRESSURE VESSEL BY RIVETING, BRAZING OR ANY OF THE METHODS OF WELDING PRESCRIBED IN THIS SECTION OF THE CODE. FOR PRESSURES LESS THAN 125 LB. PER SQ. IN. A SCREWED FITTING MAY BE USED.

PAR. U–88. REVISED:

U–88. *Inlet and Outlet Connections.* PIPE CONNECTIONS MAY BE MADE AS PROVIDED FOR IN PAR. U–59. [All connections less than 5 in., standard pipe size may be attached to forge welded vessels by fusion welding as specified in the Rules for fusion welding (Pars. U–76 and U–77). Nozzles 5 in. and over shall be attached by forge welding or by riveting.]

Nozzles which are attached by forge welding shall be of forged or rolled steel material, seamless tubing or forge-welded pipe, using either of the three methods shown at (*B*), Fig. U–4, or attached to a head by forge welding as shown at (*A*), Fig. U–4. Either the nozzle or shell may be flared for this purpose.

Scheme for the Identification of Piping Systems[1]

A Systematic Plan Employing Color and Other Kinds of Markings Based on Fundamental Principles

Object and Scope

THE Scheme is intended to harmonize all specifications for the identification of materials conveyed in piping systems and is intended to form an acceptable basis for a universal scheme.

This Scheme has been limited to the identification of piping systems in industrial plants and power plants, not including pipes buried in the ground and electric conduits.

Definitions

Piping Systems. For the purpose of this Scheme, piping systems shall include in addition to pipes of any kind: fittings, valves, and pipe coverings. Supports, brackets, or other accessories are specifically excluded from applications of this standard. Pipes are defined as conduits for the transport of gases, liquids, semiliquids or plastics, but not solids carried in air or gas.

Safe Products. These products are those involving no hazard in their handling and no extraordinarily high value. A workman in approaching a piping system to make repairs will accordingly run no undue risks in breaking into a pipe bearing a safe material, even though that material has not been emptied by previous arrangement.

Dangerous Materials. These materials are those which are in themselves hazardous to life or property by virtue of being easily ignited or productive of poisonous gases or are in themselves poisonous. They include materials that are known ordinarily as fire producers and explosives.

Protective Materials. Under this class fall materials which are piped through plants for the express purposes of being available to prevent or minimize the hazard of the dangerous materials above mentioned. Thus, a plant may have certain special gases which are antidotes to poison fumes, piped through its shops for the express purpose of release in case of danger.

Extra-Valuable Materials. These might be classified with the group of the safe materials above mentioned, but where these products have a very high value, it is preferable to give them a separate major classification.

Fire-Protection Equipment. This classification includes sprinkler systems and other fire-fighting equipment.

Method of Identification

The standard Scheme proposes the use of an identification mark made up of three distinct parts: (*a*) an identifying band of color, one of the five listed in a later paragraph, which indicates to which of the main classifications the material belongs; (*b*) a stenciled legend, abbreviated or otherwise, placed on the color band and naming the material carried; and/or (*c*) where desired additional colored stripes of contrasting hues at the edge of the color band. Combinations of the first two of these three elements and, if desired, the addition of the third are permitted in the various industries or plants, provided the main classification color bands agree with the scheme. These identification marks shall be placed at intervals throughout the piping system to insure ready identification during repair operations and in an emergency.

As an alternative to the use of an identifying band of color, part (*a*) above, the entire piping system may be painted in the appropriate main classification color. In this case the legend and/or the stripes shall be placed at convenient intervals throughout the piping system, preferably adjacent to valves and fittings.

Main Classification by Color

This part of the Scheme is intended to identify the main classes into which the materials in the piping systems belong. It establishes a basic fundamental principle applicable to all schemes for identifying piping systems and is intended to designate the pipe contents as belonging to a specific class of materials that are safe, dangerous or otherwise, depending on local conditions. The inclusion of all existing systems at present in use is made readily possible with minimum change by the adoption of the following color classification.

All piping systems are classified according to the character of material carried. Especially in an emergency the quick recognition of the contents of a piping system is of paramount importance. For this purpose each piping system is classified, by the nature of its contents, into the following classifications:

	Class	Color
S	Safe products	Green or the achromatic colors white, black, gray, or aluminum
D	Dangerous materials	Yellow or orange
P	Protective materials	Bright blue
V	Extra-valuable materials	Deep purple
F	Fire-protection equipment	Red

The above colors have been chosen to identify the main classification because they are readily distinguishable one from another. Reference to Appendix B will show in addition the relation of the colors chosen to each other and to the color circle on which the color arrangement has been based.

Red has been assigned to fire-protection equipment because of long-established custom. Yellow and orange have been assigned to dangerous materials because of all the saturated chromatic colors these have the highest coefficient of reflection under white light and can therefore be more readily recognized under the poorest conditions of illumination. Further, yellow is the traditional color of the quarantine flag and has been adopted as the caution signal for railroads and road traffic. The assignment of the other three colors follows in natural order.

Detailed Instructions for Working Out a Standard Identification Scheme[2]

List all materials carried in the pipes of the system or systems.

Assign each of these materials to one of the five main classes: Safe Products (S), Dangerous Materials (D), Protective Materials (P), Extra-Valuable Materials (V), and Fire-Protection Equipment (F).

Group the materials assigned to each class for the purpose of facilitating the selection of sub-class markings.

Choose between the alternative methods of (*a*) color bands or (*b*) complete color painting.

Assign a legend or color stripe to each material listed under each main classification.

Refer to Appendix C and select the five colored paints which will identify the main classes and the paints to be used for the stripes if the use of stripes has been decided upon in place of legends.

No type of paint or other suitably colored coating is excluded. The selection of coatings comes under the jurisdiction of the supervising engineer or person in authority and may be made to meet the diverse requirements of each case. All that the scheme requires is that the dominant hue of the band shall fall unmistakably within one or the other of the five spectral regions.

Colors which have a total reflective value too low to permit ready differentiation at minimum illumination are excluded. Median gray, which from the physiological or visual standpoint is situated about half-way between white and black, reflects approximately 25 per cent of the incident standard white light and is near the permissible limit of reflective value for poor illumination. The

[1] From Recommended American Practice proposed by the Sectional Committee on the Identification of Piping Systems, organized under the procedure of the American Engineering Standards Committee and jointly sponsored by the National Safety Council and The American Society of Mechanical Engineers.

[2] Note. The Sectional Committee on the Identification of Piping Systems has created a permanent organization to enable it to assist those firms and individuals who desire to consult it preparatory to the installation of this standard scheme. Address all communications to one or the other of the sponsor bodies.

permissible limit of reflective value is provisionally established at 19 per cent.

An ordinary hand flash lamp when held by an operator at the reading distance may be used as the arbitrary measure of minimum illumination.

Appendix A

CLASSIFICATION OF MATERIALS CARRIED IN PIPES

FOR the purpose of securing data on which to base its report, the Sectional Committee through its Sub-Committee No. 3 on Classification canvassed the various industries. This canvass was carried through by means of a questionnaire which was sent to a large number of companies typical of the industries handling large quantities of varied kinds of materials which are conveyed in pipes.

In the table which forms part of Appendix A (not reproduced here) are listed all the materials suggested in the replies to the questionnaire. In addition certain determinants of important physical characteristics are given together with the classification into the five main groups: (S) Safe Products, (D) Dangerous Materials, (P) Protective Materials, (V) Extra-Valuable Materials, (F) Fire-Protection Equipment.

The Committee found that frequently certain materials which were at one time dangerous could fall in one or the other of the classifications. After discussing the matter with representatives of the industries the Committee has come to the conclusion that "once a dangerous material always a dangerous material" should be the rule to be followed, and in the particular industry in which the dangerous material becomes the antidote or safe material, it should still be marked as dangerous. The few men who are in that industry should be directed by markings other than color to use it when necessary for their protection. In this way the hazard of having dangerous materials used on the wrong occasions for safe materials will be eliminated. An example of this is the use of ammonia, usually a dangerous material, as a safety material when attacking phosgene fumes. The contrary case, however, of a normally safe material becoming dangerous under certain conditions, should be met by having this material considered as dangerous only in those locations where it is dangerous, being classified by this committee as a safe material. An example is water over quicklime. In the case of drinking- or service-water systems with special outlets for fire protection, the Committee recommends that the fire outlets only be designated as fire protection, the remainder of the line to be classified as safe.

Appendix B

IDENTIFICATION BY COLORS

FOR quite a long time pipe lines in various industrial plants have been painted in different colors for the purpose of ready identification. Of the various color schemes heretofore devised none has been based upon any definite fundamental principle, either scientific, psychologic, esthetic, or traditional. Because the selection of colors has been arbitrary and influenced by local conditions not common to plants in general, and because a comprehensive extension of such schemes soon involves a mass of detail which automatically renders them difficult if not impracticable, the inadvisability of recommending any of them for adoption as a universal Scheme is fairly obvious.

This condition was fully recognized by the Sub-Committee on Plan and Scope, and a part of its report is therefore quoted below:

IDENTIFICATION

It is obvious that to attempt to outline a code in identification would result in a system so comprehensive that even should the supply of colors and identification symbols hold out, adoption of it would automatically be rendered impossible in those industries which do not have a major group of colors allocated to its products. It is found, however, upon investigation that any materials transported in pipes in a plant fall in one of the following classifications:

(*a*) *Safe Products.* This represents a majority of the products that are handled through a plant. These products may be defined as having no hazard in their handling and no extraordinarily high value, so that a workman in approaching a piping system to make repairs will run no undue hazard in breaking into a pipe bearing a safe material, even though that material had not been emptied by previous arrangement.

(*b*) *Dangerous Materials.* These materials are those which in themselves are hazardous to life or property by virtue of being easily flammable or productive of poisonous gases or are in themselves poisonous. They include of course materials that are known ordinarily as fire producers and explosives.

(*c*) *Protective Materials.* Under this class are materials which are piped through plants for the express purpose of being available to prevent or minimize the hazard of the dangerous materials above mentioned. Thus, a plant may have certain special gases which are antidotes to poison fumes, which gases are piped for the express purpose of affording protection in emergencies.

(*d*) *Extra-Valuable Materials.* These might be classified as a group of the safe materials above mentioned, but inasmuch as cases came to your committee's attention where those products would have a very high value, it appeared preferable to give them a separate major classification.

(*e*) *Fire-Protection Equipment.* This might properly be called a division of the Protective Materials just mentioned above, though the hazard of fire and the use of sprinkler systems and other fire-fighting equipment having become so universal, it would appear better to make it a special major classification.

These five classifications, or subdivisions thereof if necessary, in the opinion of the Committee should each be given a major color, and the various subdivisions that a plant may need can be obtained by the use of numbers, names, or the like, painted in white or black upon a background of the color selected.

The immediate problem of Sub-Committee No. 1, therefore, was to select a set of colors for these five major classes in accordance with some basic principle readily understood, easy to remember, capable of expansion, and fulfilling other requirements as to practical availability, ready visibility, resistance to various forms of attack, and indicating in some progressive way the degree of danger or safety.

In any complete color scheme of this sort the natural basis is the solar spectrum, and if the spectral hues are grouped in their natural order in the form of a circle we have the arrangement shown in Fig. 1 (not reproduced here). This color circle may be divided into five sectors, each sector or spectral region representing one of our five main classes and capable of subdivision, where necessary, into a larger number of hues having approximately similar dominant wave lengths but distinguishable from each other very readily under favorable illumination (see Fig. 2, not reproduced here).

With regard to durability, there seemed at first to be a general idea that the Committee should select five or six indestructible pigments and have paints made from these only. A little reflection soon shows a position of this sort to be untenable: first, because the resistance to attack is limited by the vehicle as well as by the pigment; second, there are few substances either in the inorganic colored pigments or the organic vehicles that are equally immune to all the various forms of attack; and third, the commercial availability of the materials from which practical and economical paints can be made is by no means a negligible factor.

The Committee therefore has concentrated its efforts on the presentation of a practical system having a sound claim to preference over any other heretofore suggested, and has avoided confusing the main point at issue with paint-production problems which may be easy or difficult of solution according to the differing conditions in different plants. On the other hand, the Commmittee has a detailed practical knowledge of what it is possible to produce in paints and has included in the system nothing beyond these possibilities. If a pipe contains extra-hazardous material the only fundamental requirement is that it should be yellow; the shade of yellow, the kind of pigment, and type of paint or other coating, are matters of detail coming under the province of the engineer in charge. All the system requires is that the yellow shall be of such a kind that it will not be mistaken for the green, blue, purple, or red of the other main classes.

To show a number of variations of colors and illustrate the flexibility of the system, a set of color chips on paper has been prepared in a dozen or more different colors, which is submitted with this report as part of Appendix C. The vehicle in these paints is highly resistant China-wood-oil varnish, more particularly useful for interior exposure where greater resistance to moisture than is afforded by ordinary linseed-oil paint is desirable. The paints will withstand temperatures up to 200 deg. fahr. for a reasonable time, and, except the reds, temperatures even higher than 200 deg. for a shorter time. For exterior exposure linseed oil will probably continue to be

the most economical all-around vehicle, but the system at all times permits any available vehicle best adapted to the prevalent conditions at any plant.

The system as suggested does not lose sight of an important fact in economical paint production, a fact which has heretofore taken a paramount position in the painting of iron and steel where the protection against corrosion has been of equal or greater importance than the color of the coating. Black, for instance, has been widely used, not only because it may be made at a low price, but also because it is practically the only paint that will withstand elevated temperatures without discoloration, has a relatively longer life under direct exposure to sunlight, and in the form of asphaltic varnishes is proof against all acids, alkalis, and sulphide sulphur compounds even in relatively strong concentrations. It is the ideal paint for pressure steam pipes, but we have taken the position that in most modern plants such pipes are insulated by various kinds of covering mostly white or nearly so, and in general not in need of any kind of paint. Such pipes may still be painted black as protection against corrosion, and the covering marked for identification by the colored bands, legends, and stripes.

The so-called metallic browns and other types of red oxide of iron have also been very largely used in low-priced anti-corrosive paints. While the reflective value of the higher qualities of Venetian red is 19 per cent, or better, the darker shades run somewhat lower, and therefore it is believed the dark browns may be excluded from the system with less sacrifice than attends any attempt to retain them.

Gold-bronze powders are of no special value and may be omitted without economic loss, but if included for any special reason would fall in the yellow or dangerous sector. Aluminum paints also are very useful in many cases and have been assigned to be used with the whites and grays to the identification of Safe Products (S).

Appendix C

DESCRIPTION OF COLOR SAMPLES

THE samples shown in Fig. 3[3] are not to be considered as covering the entire range of colors available, but are merely examples illustrating the means at our disposal for meeting the more usual types of abnormal exposure conditions.

A plant atmosphere that will ordinarily support human life without material danger to general health, may at times be charged with gases or vapors that will react chemically on many paint pigments with a resultant change in color.

By far the most common of these abnormal forms of attack come from vapors that are acidic, alkaline, or sulphureted. The dry gases are far less active, but when accompanied by aqueous vapor they penetrate the paint film, and, if reactive with the pigment, cause rupture of the film and change of color by the formation of new compounds having a different volume and color from the original pigment.

If the vehicle is sufficiently resistant it may delay such action for a longer or shorter time according to circumstances, but no paint vehicle now known is wholly impervious to osmotic penetration of this kind. In any plant, therefore, where such abnormal conditions persist, the first step is to use a vehicle having the highest practical water resistance, and then select colors in such a way that the pigment will have the least reactivity with the prevailing gas. The colors here shown indicate possibilities in this direction.

No. 1—Toluidin Red. Fairly fast to aqueous acids, alkalis, and sulphur. An organic pigment that will stand up as well as the vehicle. Adds materially to the life of varnish vehicles and works well with all of them.

No. 2—Paranitranilin Red. Similar to the toluidin and considerably cheaper, but owing to a slight solubility in the vehicle it has a tendency to stain up through light shades or whites applied over it, e.g., white letters or aluminum stripes.

No. 3. A mixed pigment consisting of an organic red similar to toluidin mixed with zinc yellow. Fast to alkalis and sulphur but not to acids. Shade of orange may be adjusted to suit. Mixed with cadmium yellow in place of the zinc yellow it becomes fast to acids as well.

[3] Fig. 3, not reproduced here, consists of 14 printed color samples intended to represent the paints referred to in Appendix C.

No. 4—Orange Chrome Yellow. The regular color for ordinary use. Fast to alkalis but not to acids or sulphur.

No. 5. Yellow ochre toned up with bright yellow to a type commonly known as golden ochre. Ochre itself as compared with the more highly saturated hues is little more than a yellow-brown, but in the proposed system where browns as distinctive colors are eliminated the ochre falls unmistakably in the yellow sector. Owing to its general stability and low price it is the main reliance for fast yellow in situations where chrome yellows cannot be used. Like other iron compounds that contain hydroxyl groups or "chemically combined water," it is not wholly fast to sulphur. Strong ammonium sulphide darkens it somewhat, but except in extreme cases it is fast to everything. When toned up to a brighter shade, the resistance depends on the kind and quantity of toner.

No. 6—Cadmium Lithopone. A combination of cadmium sulphide and blanc fixe. Fast to everything, but applicable to extreme cases only because the available supply is limited and the cost relatively high.

No. 7—Lemon Chrome Yellow. The ordinary pigment for general use. Fast to acids but not to caustic alkali or sulphur.

No. 8. Chrome oxide toned up with a little yellow to raise its total reflection value. This oxide is a moderately low-priced oxide, not to be confused with Vert de Guignet, a much more brilliant and expensive quality. It is fast to everything and useful in extreme cases.

No. 9—Ordinary Chrome Green Light. Fast to weak acids but not to alkali or sulphur.

No. 10. Prussian blue tint with a base white of Titanox. Fast to acid, fairly resistant to sulphur, easily affected by alkali.

No. 11. Ultramarine blue tint with base white of zinc oxide. Fast to alkalis and sulphur but not to acids.

No. 12. Base white of Titanox tinted with alizarine purple. Fast to everything. Shade can be adjusted by adding alizarine red.

Nos. 13 and 14. A gray and a black. Included for comparison and incidental interest.

For ordinary outside exposure linseed oil is the most durable vehicle. Where higher resistance to water is required and for interior use, China-wood-oil varnishes may be used to advantage. Where both of these fail, some type of coating other than ordinary paint must be selected or the identification by color abandoned.

Appendix D

IDENTIFICATION OF PIPING SYSTEMS BY LEGENDS

THE first efforts of Sub-Committee No. 2 centered upon a combination of symbols or hieroglyphics along with a legend naming the nature of the containing fluid, the legend with its accompanying symbol appearing prominently at the points of supply to the piping system and at points of distribution therefrom; any further marking at intermediate points along the pipe line to consist of the symbol only.

The symbol idea was later entirely discarded since it was considered impracticable because of the great mass of detail involved, the difficulty an operating force would encounter in recalling to mind the different shapes and forms and the probable necessity for publishing a code book upon the part of each operating company.

The Committee finally arrived at the conclusion that this form of identification marking should consist principally of a lettered legend, abbreviated or otherwise, naming the material carried in the pipe line. Where a knowledge of the direction of fluid flow may be of service it is suggested that arrows be painted on the pipe.

In certain types of plants it may be desirable to label the pipes at junction points or points of distribution only, as suggested in Fig. 4 (not reproduced here). In certain existing power plants the markings are repeated at intervals all along the pipe line. In any case, the operating man should decide the location and number of signs required in each particular system of piping.

With regard to visibility, the eye as a matter of habit is most accustomed to the reading of black letters on lighter backgrounds. We therefore suggest that the black letters be either stenciled or painted on the band of main classification color when light and on a rectangular background when dark. The color of the background and the nature of the material used may be that deemed suitable for the purpose. Aluminum paint serves very well for this purpose.

Engineering and Industrial Standardization

Standardization of Certain Dimensions of Electric-Motor Frames

STANDARDIZATION of certain important dimensions governing the interchangeability of electric motors of different makes has made a forward step with the recent acceptance of joint sponsorship by The American Society of Mechanical Engineers and the National Electrical Manufacturers Association. It will be recalled that a report of a general conference called by the American Engineering Standards Committee was reported in this section of the February, 1927, issue of MECHANICAL ENGINEERING.

Machinery everywhere is more and more becoming motorized, being either driven by self-contained electric motors or adapted to easy application of motor drive upon installation. This is particularly noteworthy in such fields as metal- and wood-working machinery of every description, household and commercial laundry machinery, refrigerating machines, foundry equipment, printing presses, steel mills, and so on. However, owing to variation of sizes among different makes, specific and detailed information is often necessary with each new application, and in some cases significant changes in design have been required to accommodate some particular make of motor. Sometimes, as in the case of breakdown of equipment in service, serious inconvenience has been caused, due to the impracticability of using a motor of any other make than the one originally supplied.

The National Machine Tool Builders Association, who found diversity in motor dimensions a problem of particular difficulty in their industry, filed the original request to have the subject taken up by the American Engineering Standards Committee. A conference, to which all parties interested in this subject were invited, was called by the latter body, at which the following scope for the work was recommended:

a A series of standard dimensions for the distance from the base to center of shaft (shaft height)
b A series of standard distances between bolt holes, at right angles to the shaft
c A series of standard distances between bolt holes, parallel to shaft
d Certain definite combinations of a shaft height with any or both of the distances between bolt holes as mentioned under *b* and *c*
e Maximum diameter and length of the motor.

Upon recommendation by a special committee appointed by the conference, the National Electrical Manufacturers Association and The American Society of Mechanical Engineers were appointed joint sponsors for the project. These bodies are now proceeding to the organization of a sectional committee to take up the technical work.

Specifications on Quality of Cotton Sheeting

RECOGNIZING the great value of the engineer's method of approach, the American Home Economics Association believes that the solution of the problems of industrial economics and trade generally would be greatly facilitated if this method was employed. Accordingly, this Association has requested that the American Engineering Standards Committee call a general conference of those concerned in the standardization of the quality of sheets in order that nationally recognized specifications for sheets and sheeting may be developed. This request is pursuant to unanimous action taken by the American Home Economics Association at its meeting in Asheville on June 22, in approving the work of its Standardization Committee.

The calling of such a conference was also requested by a unanimous recommendation of those present at a conference called in Washington, D. C., on June 10, by the Division of Simplified Practice. The Washington Conference represented several departments of the federal and state governments, the American Hospital Association, the Cotton Textile Institute, a department-store chain, the Y. W. C. A., the Y. M. C. A., the General Federation of Women's Clubs, other interested organizations, and the accredited representative of over 50,000 consumers.

It is understood also that the National Retail Dry Goods Association, the principal distributers of sheets and sheeting at retail, is fully in favor of bringing this matter before a national conference for discussion.

As the accredited representative of the Association, Rosamund C. Cook, professor of Home Economics Education of the University of Cincinnati, was authorized to make this request on behalf of a number of consumer groups before whose meetings she had presented the pressing difficulties in the purchase of sheeting by the ultimate consumer and the impossibility of buying such material at retail in a way which will insure maximum value for the expenditure. These organizations are:

Division of Home Economics Teaching, Mrs. J. C. Grawler, *Chairman*, General Federation of Women's Clubs
Division of American Home, Mrs. Maggie Barry, *Chairman*, General Federation of Women's Clubs
Boston City Federation (65 Women's Clubs)
The National Consumers' League
The Cincinnati Consumers' League
20 State Home Economics Associations
6 Home Economics Clubs (one alone representing 474 members)
Ohio Hotels Association
178 Home Economics teachers and leaders (one state leader alone representing over 18,000 persons). There are other groups of influence whose promise of support has been given and whose petitions will follow.

Enclosed with the request were copies of a leaflet which had been prepared with the title, "What Price Sheeting?" This presents in brief compass the results of the laboratory work on sheets sold, an analysis of the market conditions confronting the ultimate consumer, and other material of interest.

Recognition was made in the letter of the A.E.S.C.'s ability to provide for a meeting of all essential interests, commercial, technical, and industrial, and in view of the complexity of this question and its great economic importance, an earnest hope was expressed that the American Engineering Standards Committee will act favorably on this request. So far as the writer of the letter is informed, this is the first time that manufacturers and consumers have together attempted such a piece of work and it is felt that the American Engineering Standards Committee will appreciate the significant value and importance of a favorable and acceptable outcome.

In making this request the A.H.E.A. points out that although the request originated with the consumer, following the vote of the Washington Conference, the matter became a trade problem and as such is eminently in that field. In this connection it suggests that the approach desired to this problem is definitely an engineering one of specifications based directly upon laboratory and other test data.

Every one, including engineers themselves, has felt the great aid that could be brought to the economics of industry and trade generally by the use of the engineering approach to the solution of commercial and industrial problems. It is believed that this is such a problem and that the issues involved as between the producer, the consumer, and the general public are identical in all essentials with the problems which the A.E.S.C. regularly aids the solution, as in such cases as the Gas Safety Code, the work on standardization and specifications for plumbing equipment, standardization of paper sizes, galvanizing of hardware, and other projects already before the A.E.S.C.

The last few years have seen a very beneficial development of engineering methods into such fields as, for example: development of standards and methods of test for shellac, turpentine, linseed-oil paints, cotton thread, rayon and knit goods, screen wire cloth, resistance wire for household electrical appliances, kerosene, gas logs, and kitchen gas ranges, which are now being developed under committees of the American Society for Testing Materials and the American Gas Association.

It was the desire of the meeting in Washington, already referred to, that the general national conference, if authorized, should be convened in the present month or as soon thereafter as possible.

Safety Code for Textiles

SOME time ago the National Safety Council accepted the invitation of the American Engineering Standards Committee to act as sole sponsor for the Sectional Committee which is to develop a Safety Code for Textiles. Following the regular procedure the N.S.C. communicated to the national organizations interested in this project, requesting them to appoint official representatives on this Committee. It has now presented the personnel of the Sectional Committee to the A.E.S.C. for approval.

The following wording of the scope of the Project known as "A.E.S.C. L 1" has been agreed to: Safety provisions for (1) cotton mills and mills operating machines used to make unbleached cloth from cotton, including pickers, cards, combers, drawing frames, slubbers, roving frames, ring spinning frames, spinning mules, spoolers, twisters, warpers, flashers, looms, inspection machines, folding machines, and baling presses; (2) plants engaged in bleaching, dyeing mercerizing, printing, and finishing textile fabric, and to plants operating sewing machines, cloth sinters, washing machines, kiers, mercerizing and tenter frames, mangle winders, dry cans, dyeing padders, jigs and gats, color mixers, printing machines, soapers, aging boxes, pasters, dampeners, calenders, hookers, doublers, baling presses, extractors, and beetles; (3) and other textile operations.

The proposed personnel of the Sectional Committee on Safety Code for Textiles is as follows:

CHARLES H. EAMES, *Chairman*
W. DEAN KEEFER, *Secretary*
CYRIL AINSWORTH, Department of Labor and Industry, Harrisburg, Pa., representing the Association of Governmental Labor Officials of U. S. and Canada
W. D. BARKER, Lockwood, Green and Company, Boston, Mass., Member at Large
F. G. COBB, Secretary and Treasurer, Southern Textile Association, Lancaster, S. C., representing the Southern Textile Association.
H. W. DONALD, American Mutual Liability Insurance Company Boston, Mass., representing The American Society of Mechanical Engineers
CHARLES H. EAMES, President, Lowell Textile School, Lowell, Mass., Member at Large
JOHN HANLEY, Lowell, Mass., representing the U. S. Department of Labor
W. DEAN KEEFER, Director, Industrial Safety Division, National Safety Council, Chicago, Ill., representing National Safety Council
EVERETTE F. KING, H. A. Hale, Jr., and Company, Boston, Mass., representing the National Association of Wool Manufacturers
W. A. HUMPHREYS, Secretary, National Association of Wool Manufacturers, Boston, Mass. (Alternate to Mr. E. F. King)
A. C. MARBLE, Curtis and Marble Manufacturing Company, Worcester, Mass., Member at Large
ARTHUR MCDONNELL, Philadelphia, Pa., representing the U. S. Department of Labor
IGNATIUS MCNULTY, American Woolen Company, Boston, Mass., representing the National Safety Council
JOHN P. MEADE, Director, Division of Industrial Safety, Department of Labor and Industries, Boston, Mass., representing the International Association of Industrial Accident Boards and Commissions
H. L. NICKERSON, Crompton and Knowles Loom Works, Worcester, Mass., Member at Large
JOHN A. PERKINS, Agent, Harmony Mills, Cohoes, N. Y., representing the National Association of Cotton Manufacturers
RUSSELL T. FISHER, Secretary, National Association of Cotton Manufacturers, Boston, Mass. (Alternate to Mr. J. A. Perkins)
C. E. PETTIBONE, Vice President and Chief Engineer, American Mutual Liability Insurance Company, Boston, Mass., representing the National Association of Mutual Casualty Companies
KELSEY G. REED, K. L. Gilmore and Co., Somerville, Mass., representing the National Association of Finishers of Cotton Fabrics
HARVEY SAUL, U. S. Finishing Company, Providence, R. I., representing the National Safety Council
C. W. SCHOFFSTALL, U. S. Bureau of Standards, Washington, D. C., representing the U. S. Bureau of Standards
H. M. STANLEY, Chairman, Industrial Commission, Atlanta, Ga., representing the International Association of Industrial Accident Boards and Commissions
DAVID VAN SCHAACK, Bureau of Inspection and Accident Inspection, Aetna Life Insurance Co., Hartford, Conn., representing the National Bureau of Casualty and Surety Underwriters.

Nominalism and Academic Snobbery

THE word "research" is in danger of becoming an invidious term. At one extreme it is being cheapened, like the word "engineer," by use as an artificial stimulant of unworthy causes—a too common abuse nowadays in the exploitation of high-sounding words by self-seeking interests. At the other extreme there is danger of what might be called research snobbery—a pose assumed by pedantic formalists who assert that only their kind of research is "pure." No less an authority than the president of Columbia University has stated that the word "research" is being used to cover a multitude of sins. He referred to members of a university who go through pretentious motions and glean little pepper-kernels of insignificant fact in order to make much to-do over trivialities.

Some professors of chemistry or biology throughout the country would deny that there is such a thing as "engineering research." These pure scientists cherish a false pride of caste and an almost religious prejudice against anything associated with that they call "trade." To them, so gross and commercial an application as engineering could never be associated with so sacred a word as "research." Their convictions are so closely wrapped up with self-aggrandizement and what the preacher calls "vanity of vanities" that there is not much hope that they will broaden their views until the sense of the ridiculous overtakes them. Happily, but few scientists continue to harbor such convictions. Coöperation between scientists and engineers has become intimate and mutually helpful.

Engineering research has fairly well crystallized out as a legitimate and meritorious activity. It has passed through its period of adolescence and nose-to-the-grindstone, and is now on a scientific and objective basis. Mercenary considerations have been mellowed by altruism and a professional spirit—much as is medical research, for a concrete analogy. An engineer experimenting scientifically in a research laboratory on the properties of metals is just as truly serving mankind and alleviating its problems as any bacteriologist in the Rockefeller Institute, and is just as truly disclosing laws of nature as any professor of chemistry who applies Gibbs' phase rule to an untried combination of elements.

Much engineering research is, of course, done for commercial profit, more or less directly. A corporation such as the General Electric Company cannot afford to engage a Langmuir or a Steinmetz unless there is some indirect advantage in prospect. But an increasing number of industrial corporations are taking a long, broad view of what constitutes profit. Still more detached and altruistic is the research work of such an institution as the Engineering Foundation.

This Foundation was the creation of Mr. Ambrose Swasey, eminent engineer, telescope builder, and machine-tool maker of Cleveland, with the aid of friends in the engineering societies. Having gained a fortune in engineering, Mr. Swasey determined to benefit his profession in a lasting and idealistic way. Instead of establishing a foundation which would bear his name but to which contributions of other philanthropists would be unattracted, he devised the happier plan of placing funds in charge of the four national engineering societies in order to encourage and elevate engineering research of a kind not otherwise likely to be carried on. This generous gift to establish the Engineering Foundation was intended as the beginning of a trust for the country's engineering community—a trust which would grow to great size by additions from other persons interested in, or profiting by, engineering. And who does not profit by engineering?

What has happened since 1914 when the Foundation was established, and what is hoped for the future, will be told in a later article.

P. B. MCDONALD.[1]

The Portland Cement Association, which now maintains 31 district offices covering the United States and British Columbia, and the American Gear Manufacturers' Association, consisting at present, of 94 member companies, have become member bodies of the American Engineering Standards Committee, with direct representation on its main and executive committees.

[1] New York University.

The Conference Table

THIS Department is intended to afford individual members of the Society an opportunity to exchange experience and information with other members. It is to be understood, however, that questions which should properly be referred to a consulting engineer will not be handled in this department.

Inquiries will be welcomed at Society headquarters, where they will be referred to representatives of the various Professional Divisions of the Society for consideration. Replies are solicited from all members having experience with the questions indicated. Replies should be as brief as possible. Among those who have consented to assist in this work are:

ARCHIBALD BLACK,
Aeronautic Division
H. W. BROOKS,
Fuels Division
R. L. DAUGHERTY
Hydraulic Division
JAMES A. HALL,
Machine-Shop Practice Division
CHARLES W. BEESE,
Management Division
G. E. HAGEMANN,
Materials Handling Division
J. L. WALSH,
National Defense Division
L. H. MORRISON,
Oil and Gas Power Division
W. R. ECKERT,
Petroleum Division
F. M. GIBSON and W. M. KEENAN,
Power Division
WINFIELD S. HUSON,
Printing Machinery Division
MARION B. RICHARDSON,
Railroad Division
JAMES W. COX, JR.,
Textile Division
WM. BRAID WHITE,
Wood Industries Division

Oil and Gas Power

Crankless Oil Engines

OG-9 With what success has the crankless type of oil engine been used? Give operating results and maintenance figures, length of time in continuous successful operation, and any additional information tending to establish the position of the engine in the power field.

(*a*) The above question, published in the September, 1927, issue, page 1027, is not sufficiently specific; a crankless type of oil engine can be of several types. A free-piston Diesel-type oil cylinder direct connected to a special type of pump for deep-well service has been successfully operated in an experimental plant in California. The free piston, direct connected to a piece of pipe 40 ft. long with a valve in the bottom, was hung in a well about 40 ft. in depth. There was no crank and the only flywheel effect was the oscillation of the column of water in the tube. This caused the pistons to give characteristic Diesel cards. The results were as follows, one up-and-down motion constituting a cycle:

Lift	Cycles per min.	Gallons per min.
20 ft.	190	2400
30 ft.	185	1900

Fuel-economy tests using fuel oil of 28 deg. gravity gave a consumption per water hp-hr. of from 1 to 1.25 lb. These figures were obtained with a full-Diesel, two-stroke-cylinder oil engine with solid injection, $10^1/_2$ in. bore and $14^1/_2$ in. stroke. The piston was of the single-acting type, and had a larger piston 20 in. in diameter above it, acting as a cushion on the up stroke, at the same time compressing scavenging air which completely scavenged the cylinder just after the exhaust had taken place.

The water being accelerated by the explosion of the oil under the piston and by the lifting of the tube with its valve, continued its upward motion as the tube was retarded by the cushion, and fresh water came in through the valve as the tube returned. The weight of the tube compressed the air in the cylinder and fired the spray charge. The consumption of 1 to $1^1/_4$ lb. of heavy Diesel oil of about 18,000 B.t.u. per water hp. for a cylinder of but 25 hp. capacity, showed a fairly good efficiency, which would, undoubtedly, be much better with a larger machine.

Another cylinder was operated in a well 70 ft. deep with approximately the same results. (Edward N. Trump, Mechanical Engineer, Syracuse, N. Y.)

(*b*) In answer to the above question, which was published in the September, 1927, issue, the writer would say that the crankless engine patented by A. G. M. Michell of Melbourne, Australia, has been developed by Crankless Engines, Ltd., at their experimental works in Melbourne. The applications now in commercial use comprise oil and water pumps, air compressors and boosters, gasoline and producer-gas engines. This company has recently built experimental oil and Diesel engines on this principle, but it is too early to give any details regarding operation and maintenance. Some of the installations to date are two 50-hp. gas engines supplied to the Australian Gas Light Company, Sydney, in 1924; three 75-hp. engines to the same company in 1925; one 50-hp. engine to the Colonial Gas Association, Melbourne, in 1926; and one 100-hp. engine to the South Australian Gas Company in 1925. These engines were all built for direct connection to crankless gas boosters. Each of the above companies have since ordered 300-hp. crankless gas engines, ten in all, which are being manufactured by the National Gas Engine Company of Manchester, England, under license. Four of these engines are on their way to Australia after having completed very satisfactory works tests.

The original engines have been doing continuous duty, averaging six to eight hours per day since their installation at considerably less cost than the units they replaced. Details of maintenance costs are not available at the moment, but that they are low is evidenced by the fact that the users have given repeat orders and the manufacturers have not been called upon to renew any engine parts whatever up to this date.

Two British firms and one French firm are now building Diesel engines under license.

Two automobile engines of 35 hp., N. A. C. rating, were built in 1923 and are still running in Buick chassis in Melbourne. They have a high mechanical efficiency and a very low lubricating-oil consumption. Two smaller types of automobile engine are now being constructed in Melbourne and in England. (J. H. Lindon, Engineer, Crankless Engines, Ltd., Melbourne, Australia.)

Railroad

Back Pressure in Locomotive Cylinders[1]

R-13 What has been done to reduce or eliminate back pressure in the cylinders of a locomotive? It is understood that back pressure is one of the prime reasons for the relatively low efficiency of the steam locomotive. The back-pressure problem has been solved in power-plant operation, why can't it be done on the steam locomotive?

Regarding the above question, which was discussed in Mechanical Engineering of September, 1927, page 1027, the writer would point out the following:

Back pressures in steam locomotives range from 15 to 30 lb. per sq. in. This seriously reduces the power obtainable from the cylinders, and increases the steam and coal consumption. By increasing superheat and increasing pressures the efficiency of the locomotive has been improved, but the problem of successful use of the condenser on the locomotive has never been solved. When running at full load a locomotive has a pressure at the beginning of exhaust very much higher than the back pressure, and the area of a card, carried out to even atmospheric pressure, is a very considerable percentage of the useful work.

Dr. Johann Stumpf, the inventor of the uniflow engine, has designed several uniflow locomotives, several of them having been built and put in successful operation in Germany. But recently there have been built for Russia locomotives which have, in addi-

[1] This subject has been discussed in a previous issue.

tion to the uniflow cylinders, induced-exhaust nozzles, arranged so that the exhaust from one cylinder, passing out under the high back pressure, exhausts the steam from the other cylinder, at the same time maintaining the pressure on the draft nozzle. The best results were obtained with three-cylinder locomotives, as the time of exhaust is more favorable for the reduction of pressure in the other cylinders. The energy in the toe of the card was thus utilized to maintain a low pressure in the cylinder, which is especially important for uniflow engine as the compression is much lower, less clearance can be used, and the useful work as shown in the card is increased. The pressure in the cylinders was reduced to 0.5 atmos. abs., instead of 15 to 30 lb. back pressure. The draft nozzle functioned perfectly, making a much more uniform draft, throwing much less fine coal and cinders from the stack, and making very much less noise than is usual in locomotives.

No locomotives of this type have been built in this country, as the three-cylinder locomotive, which would be the most favorable application, has not yet been well developed.

Multiple-cylinder, high-speed, uniflow engines are now being built with the same type of induced-exhaust nozzles. This type of engine will be especially useful in plants which use the exhaust for heating buildings. (Edward N. Trump, Mechanical Engineer, Syracuse, N. Y.)

Miscellaneous

MANUFACTURE OF STEEL WOOL

M-10 What materials, processes, equipment, etc., are used in the manufacture of steel wool such as is used for cleaning pots and pans, etc.?

1 Steel wool has by far the largest production of metal-wool products. Metal wool is a multi-knife-edged shaving in distinction from that type of material made by rolling round wire flat, such as tinsel. The usual number of knife edges is three, but in general there will be a percentage of strands having four or five included with the three-edged fibers.

2 Steel wool is manufactured in long fibers, each of which is very uniform in appearance. It is manufactured in nine standard grades, the finest of which has no fibers greater than 0.0005 in. thick and the most-used grade, No. 0, has fibers that vary between 0.002 and 0.004 in. In the medium grades the long, uniform fibers resemble wool, hence its name of steel wool; in the finer grades it resembles silk.

3 The principal uses of steel wool are for abrasive purposes, in which it is a competitor of sandpaper, pumice, etc., and carries a similar nomenclature. Secondary uses, such as gas filtering, etc., are coming into vogue, and there are several other small applications of metal wool. The product known to the trade as "Brillo," principally used for cleaning pots and pans, is manufactured by a secret process.

4 Many different raw materials and processes have been suggested for the manufacture of steel wool, but all manufactured in this country at present is made from wire. A very high-tensile—from 125,000 to 175,000 lb. per sq. in.—low-carbon, uniform-quality, almost entirely bessemer wire is used. There are few manufacturing processes which subject the wire to such a test as the making of wool, because in its manufacture three-quarters of the wire is shaved a thousandth at a time, or thereabouts, and each fiber has to be uniform with respect to its neighbor. The manufacture of wool wire is a very difficult art in itself.

5 Two principal types of machine are used. In one type the wire is dragged over a track, and while passing over this track is shaved by a stationary knife bearing down upon it. This shaving-block type of machine was originally invented by Messrs. Marti and Müller, and has been modified and developed greatly in this country, having been the standard until 1926, when the first Brillo-Field machine was put into full operation. One Brillo-Field machine now supplies 40 per cent of the steel wool consumed in the United States, and a second machine will start operating early in 1928. This type of machine varies from the shaving-block type in that the consumable part of the wire is completely shaved in one continuous operation, and while being so shaved is wrapped about a series of tractor-driven wheels, so that the energy required for the cut is transmitted directly from the motor to the wire at approximately the point of contact with the knife. Full details are given in a paper presented to the A.S.M.E. for later publication. (Col. Crosby Field, Vice-President, Brillo Mfg. Co., Brooklyn, N. Y.)

Correspondence

CONTRIBUTIONS to the Correspondence Department of Mechanical Engineering are solicited. Contributions particularly welcomed are discussions of papers published in this journal, brief articles of current interest to mechanical engineers, or comments from members of The American Society of Mechanical Engineers on activities or policies of the Society in Research and Standardization.

Measurement of Static Pressure

TO THE EDITOR:

The writer has read with great interest the paper by Carl J. Fechheimer on the Measurement of Static Pressure, published in the July issue of MECHANICAL ENGINEERING. It happens that, while working in the compressor and centrifugal-pump testing laboratories of Brown Boveri & Company, Ltd., Baden, Switzerland, between 1919 and 1923, he carried out a number of experiments himself in this line, and out of the experience thus gained he begs to submit what follows as a small contribution to the discussion of the subject.

In studying conditions of flow in the air passages of compressors it is very desirable to have reliable devices for finding the direction and magnitude of the velocity and also the static pressure at points in the interior of the air flow. The design of such an instrument should allow for inserting it through drilled holes in the casing wall of the compressor. The whole apparatus must be so simple that it can be built by mechanics of average ability without sacrifice in accuracy of the measurements. After considerable experimenting with various types and shapes of measuring tubes, the writer was fortunate in finding a method which, on account of its reliability and the simple apparatus it requires, has since been adopted for all measurements of this sort in the Brown Boveri testing laboratories.

The device consists of a straight piece of tubing which is closed at one end by a plug and has a hole drilled in the cylindrical wall, the other end being connected to a manometer. Externally the instrument therefore resembles very much the one described by Mr. Fechheimer, except of course that it does not have a second hole in the cylindrical wall nor an inner tube to which that hole is connected.

The method of applying the device is based on the typical form of distribution of static pressure and velocity head about the circumference of a circular cylinder, which distribution is illustrated in Fig. 5 of Mr. Fechheimer's paper. The way in which this law of distribution is utilized for the measurement is somewhat different from the one described by Mr. Fechheimer, and will therefore be briefly explained.

It is assumed that the pressure indicated by the manometer on the tube can be considered as the sum of the static pressure $P_{stat.}$ plus a magnitude varying directly with the velocity head $P_{dyn.}$ Accordingly we write:

$$P_{measured} = P_{stat.} + KP_{dyn.}$$

wherein K is a constant.

As may be seen from Fig. 5 of Mr. Fechheimer's paper, the distribution of pressure about the cylinder's circumference has a well-pronounced maximum at the point 0 deg., that is to say, directly opposite the oncoming air flow, while there are minima at two points approx. 70 deg. to the rear of the first point on both sides. The curve of pressure extends at an approximately constant level between + 140 deg. and — 140 deg., i.e., over an angular range of about 80 deg.

The tube is now applied for measurement as follows: After being inserted into the air current it is slowly rotated about its longitudinal axis until the manometer indicates a maximum pressure. This is measured, and at the same time the angular position of the

tube is recorded, as it indicates the direction of the air flow. After this the tube is turned approximately 180 deg. from the first position and the pressure again read. According to the foregoing paragraph the two pressure readings, which from now on will be referred to as P_0 and P_{180}, can be considered as related to $P_{stat.}$ and $P_{dyn.}$ as follows:

$$P_0 = P_{stat.} + K_0 P_{dyn.}$$
$$P_{180} = P_{stat.} + K_{180} P_{dyn.}$$

The constants K_0 and K_{180} must be obtained in the regular way by testing the instrument in the wind tunnel. In all cases K_0 was found to be within the range of 0.975 to 0.985 of the value measured by a pitot tube, while K_{180} was found to about —0.97 of that value.

Once the instrument constants K_0 and K_{180} are known and P_0 and P_{180} have been measured in the air flow, it is easy to calculate by means of the above two equations the unknown magnitudes $P_{stat.}$ and $P_{dyn.}$ They are:

$$P_{stat.} = AP_{180} - BP_0$$
$$P_{dyn.} = C(P_0 - P_{180})$$

A, B, and C are instrument constants derived from the test constants K_0 and K_{180} and have the following values:

$$A = \frac{K_0}{K_0 - K_{180}}; \quad B = \frac{K_{180}}{K_0 - K_{180}}; \quad C = \frac{1}{K_0 - K_{180}}.$$

With $K_0 = 0.98$ and $K_{180} = -0.97$, for example, we obtain:

$$P_{stat.} = 0.5025P_{180} + 0.492P_0$$
$$P_{dyn.} = 0.4975(P_0 - P_{180}).$$

All pressures in the above formulas are absolute.

EDWARD H. SIDLER.[1]

Merchantville, N. J.

Solid-Fuel Internal-Combustion Engines

TO THE EDITOR:

In MECHANICAL ENGINEERING of December, 1926, p. 1466, an internal-combustion engine was described which was said to have been built by me and to have been in operation for more than 1000 hours. This statement is not correct. In former years I was interested in this idea of an internal-combustion engine burning solid fuel, but my interest was mainly theoretical. I do not consider that such an engine can be practically carried out.

DR. SCHNURLE.

Cologne-Delbrück, Germany.

[The description of the engine attributed to Dr. Schnürle was reprinted verbatim from another journal. The statement made in our abstract regarding successful operation for 1000 hours referred to another design of powdered-fuel engine.—EDITOR.]

The Light Supercharged Diesel Engine for Use in Air Service

TO THE EDITOR:

The paper by Mr. Elmer A. Sperry on the above subject which appears in MECHANICAL ENGINEERING, July, 1927, p. 723, has been studied by the writer with considerable interest. There are a few ideas involved in it, however, which he desires to discuss.

The engine described appears to be about the same in basic principle as the three-cylinder oil engine covered in Mr. Sperry's paper before the A.S.M.E. about five years ago. The chief claims for that engine were light weight and high efficiency, as in the case under discusssion.

On page 726 of the July issue it is stated that the expansion of the gases can be carried down to 10 or 12 lb. gage, and that a mean effective pressure of 300 lb. is produced by high supercharging, etc.

It is inevitable that for any given engine, supercharging will increase the power per unit of engine weight because the m.e.p. is increased and it is also a certainty that the terminal pressure will be increased.

From Mr. Sperry's paper it appears that m.e.p. is increased simultaneously with reduced terminal pressure or increased expansion ratio. It seems that the 300 lb. m.e.p. is referred to the area of the combustion cylinder and not the large cylinder which performs the second stage of the expansion. It is a fundamental principle of all work in analyzing cycles of steam engines, oil engines, air compressors, or any other machines to base m.e.p. on the maximum volume of the vessel in which the gas is handled, i.e., the low-pressure cylinder displacement. On this basis the 300 lb. would be reduced considerably, depending on engine-cylinder dimensions or ratio.

With regard to the advantage of securing low terminal pressures, there is a grave doubt that any improvement of efficiency can be secured by going as low as 10 or 12 lb. It is more likely to result in a net loss for the following reason.

Assume the m.e.p. referred to the low-pressure cylinder to be 100 lb. operating at sea level. About 80 per cent mechanical efficiency is a fair assumption for a two-cycle oil engine. Then 20 per cent of the 100 lb. (or 20 lb.) of this m.e.p. is required just to keep the engine moving at normal speed if it delivers no useful power, hence the theoretical terminal pressure should be 20 lb. to avoid having the engine lose power at a part of each stroke. This does not mean a negative loop at the toe of the card but is a fundamental idea common to steam-engine practice, and equally applicable to oil engines. Actually the terminal pressure should be several pounds above the 20 assumed in order to help overcome valve wire-drawing resistance.

If the proposed engine is similar to the compound engine dealt with in Mr. Sperry's paper five years ago, actually it is not supercharged at all because the displacement of the piston taking in free air at the bottom end of the large cylinder is less than the displacement of the low-pressure working cylinder by the volume of the piston rod at the lower end. This explains the low terminal pressure.

There are two features of Mr. Sperry's engine that would tend to make it light for its power and which have little to do with m.e.p. and have not been mentioned, the writer believes, thus far in any discussions or articles. The first relates to the mechanical design, which is so arranged that the shaft, bearings, rods, etc., receive their full working stress a larger part of the time than is the case in the usual types of engines excepting possibly a two-cycle double-acting engine. In other words, the "stress load factor" is increased over that of the usual type of engine of the same speed. The second consideration is that when the working gases are under high pressures they are handled in a small cylinder which does not need to be so thick or heavy as a large-diameter cylinder; also the piston area being less, the given unit pressure does not produce as great a total load on piston, rods, shafts, housing, bearings, and bedplate, requiring, therefore, less metal to carry the load within proper stress limits. Of course there is the low-pressure cylinder to consider, but it would seem reasonable to expect a lighter engine than the usual two- or four-stroke type for the same reason that multiple-expansion reciprocating steam engines of a given piston speed and steam pressure are lighter than the large single-cylinder steam engines that were and still are used with side-wheel vessels.

The only advantage of a compound steam engine as regards efficiency is to reduce cylinder condensation losses (witness the uniflow engine), therefore when dealing with a fixed gas there appears to be no advantage in compounding. In fact, there is a certain valve or receiver loss present to lower the efficiency.

As the writer sees it, the only advantage possibly obtainable with the proposed engine is that the mechanical design might be so arranged as to keep the various parts more fully stressed to their maximum allowable limit all the time than is now the case in other engines. This would be approaching the ideal in an internal-combustion turbine just as in the case of steam power machinery, for the lower weight of the turbine is due to the fact that the stresses in the working parts can be kept up to a uniformly high allowable limit at a maximum safe speed.

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MECHANICAL ENGINEERING

A Monthly Journal Containing a Review of Progress and Attainments in Mechanical Engineering and Related Fields, The Engineering Index (of current engineering literature), together with a Summary of the Activities, Papers and Proceedings of

The American Society of Mechanical Engineers

29 West 39th Street, New York

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Mathematics—How Much?

ENGINEERS are always debating the question of mathematics. Some, whose work has led them far along the paths of physics and research, are conscious of the fact that in spite of what extraordinary ability they may possess in mathematical lines they could do better with more, while others, whose environment is the shop, the market, or the office, will tell you, often with a smirk of pride, that the calculus is one subject they have never used. These great extremes in the engineering world give an equal latitude to a discussion of the question, "How much mathematics does an engineer need?"

It goes without saying that the natural aptitudes of young men will guide them in the choice of a profession, and there is little danger that those who have no "head for figures" will find themselves in research laboratories, or that those who have great mathematical ability will be satisfied with the more commercial aspects of engineering. There is room in the profession for men of both and all of the intervening types.

The great problem in engineering mathematics, it seems to us, is not so much that of the quantity of mathematics needed but the quality of what is taught. We have written many times of mathematics as a tool, a point of view which seems so obvious that it needs no elucidation. Without detracting from its cultural and disciplinary value, we see for the engineer an intensely practical need for mathematical consciousness as an aid in his collegiate studies, in his early years as designer or laboratorian, and in his subsequent study of the advances in the realms of science and engineering which, as a cultured citizen, cannot fail to make an appeal to his interest throughout his entire life. There are men who are naturally gifted mathematically, or who have been so rarely taught that they are apt students. We know of one young man, for instance, who, on a single rainy Sunday, solved all the problems in a book of differential equations which he was to use in a course which had not yet begun. We know of others, and there are more of these, who grope unintelligently through books and courses, never sensing the significance of their objective. Many men with naturally intelligent minds have a fear of mathematics, and this is their greatest handicap. They are victims of unintelligent and uninspired teaching which has alienated their minds.

The teaching of mathematics to engineering students is improving. The formal courses in "analytics" and "calculus" are disappearing and in their place come courses in mathematics in which, by an easy and logical development which leaves the student largely unaware of classical divisions, mathematics itself, as a useful and well-proportioned tool, fit for the hand of a normal man, takes form and consciousness. The student wakes to find that he has been using the calculus without having heard the dread word spoken, and his confidence in his ability is increased.

The average engineer probably does not use as much mathematics as he was taught, but the engineering schools are wise to retain in their curriculums as much as will insure a well-balanced training, provided it is well taught. While more mathematics than is necessary will never do any harm, too little is likely to be a grave handicap.

"Circenses"

THE Roman mobs asked of their emperors just two things: "Panem et Circenses"—bread and gladiatorial games. The mobs wanted to see blood flow, and the emperors, being wise, afforded them plenty of opportunities to do so.

It is very unfortunate that, particularly within the last few months, the development of aviation has tended more and more to assume the Circenses spirit, with more attention being paid to titillating the mob's craving for exploits involving personal danger rather than to the progress of a new art of transportation which is beginning to show promise of great value.

With the exception of one or two instances, such as the wonderful Lindbergh flight across the Atlantic and the Army flight across the Pacific, the log of an aerial performance has run somewhat as follows: The flight began with a long list of announcements as to its being taken and then put off. Some enterprises of this character have been in this stage for several months now and promise no emergence therefrom. When ultimately a flight did start the next thing heard about it was that the plane had crashed at rising or within a very short distance from the start, or else that efforts were being made, successful or otherwise, to recover the aviators from the briny deep. It is no wonder that public confidence in aviation, which was at such a high level after the Lindbergh flight, has been steadily fading away and is in danger of disappearing completely. And yet a very simple engineering analysis of the problem shows that the failures of such flights as that of Miss Doran across the Pacific have absolutely nothing to do with safety of flying as it should be properly understood.

Engineers know that all machinery has its limits and that no machinery except for experimental purposes should be permitted to be operated beyond its reasonable safe limit. The locomotive of the Twentieth Century Limited could easily pull a train at 90 miles an hour, but it is not permitted to do so because engineers know that while such a feat is physically possible, the chance of failure of rails, switches, rolling stock, and man power under such conditions would be so great as to make disaster at some time or other fairly certain. Because of this, trains are always operated (or at least always should be operated, and in the majority of cases are) considerably below the possible maximum limit of their speed or load.

It is true that at times it becomes necessary to test machinery under conditions beyond every reasonable factor of safety. In aeronautics in particular this has to be done quite frequently, and, for example, at McCook Field in Dayton there is a rig in which propellers can be tested at speeds which result in their flying start. Locomotives are sometimes run for experimental purposes at speeds that would not be permitted in regular operation, and flights like those of Lindbergh, Chamberlin, and Byrd across the Atlantic and Maitland across the Pacific belong to this very class of tests, and are fully justified.

When, however, engineers are testing locomotives at unusual speeds they do not place a young school teacher or a sixty-two-year-old princess in the cab to settle the question of who will be the first woman to ride in a ninety-mile-an-hour locomotive. Neither do engineers when they wish to make a test of the utmost limits of a piece of machinery, just hurriedly assemble the parts and subject it to a test in which human life is endangered without finding out by preliminary tests whether the machine is right, and yet this

very thing was done by one of the fliers in the Dole Transpacific Competition. It is a wonder and a testimony to the high state of development of aeronautics that the fliers survived even under these conditions, and it certainly would not have proved that flying is unsafe had they been lost.

To an engineer all of this becomes perfectly clear as soon as the facts are known. The public, however, neither knows the facts nor is the majority of it capable of giving them a proper interpretation. For the sake of the new art of aviation something should be done to prevent its being used in the spirit of a gladiatorial game, merely to provide excitement for the mob and to endanger the life of well-meaning but ignorant people. It has already been suggested that air competitions and long-distance flights be placed under the control of the Government. However, there are many in the United States who object to the extension of the power of the Federal Government and to its control of citizen activities beyond the absolutely necessary minimum, and perhaps enlightened publicity such as could be given by the engineering press and the better class of general publications might solve the problem. The main thing to realize, however, about which there can be scarcely a doubt, is that the flying disasters of this summer, particularly those on the two oceans, mean not that flying is dangerous in itself, but that unreasonably dangerous flights have been attempted and some of them have failed.

The Motor-Car Saturation Point

THE question of the motor-car saturation point is practically as old as the automobile industry itself. There was a time when the prediction that three hundred thousand cars would be built in a single year was branded as a wild dream. The registration in the United States today exceeds twenty million, and it is not yet clear whether we are approaching the saturation point or not. The unquestioned fact is, however, that we have not reached it yet.

The problem may be viewed from several different angles. In the early days of the automobile industry the question was merely whether or not enough persons could be found to buy motor cars. It was claimed that the expansion of the industry then taking place was unanimous, as attested by the fact that people were mortgaging their homes in order to buy cars. Such a situation, if true, could not have lasted and the number of buyers would have been quickly exhausted, thus putting a stop to the growth of the industry. Events have shown, however, that the foregoing reasoning was faulty in its premises, and that those who were buying cars could actually afford to do so. As the wealth of the country increased, more and more cars were bought until the industry reached its present gigantic proportions. The various estimates made of the number of persons in the country who could afford to buy cars and the like have generally indicated a limit which has been exceeded by actual production within a few years, with cars still continuing to be sold.

Of late another view has been advanced, supported among others by a man as prominent in the industry as Alvan Macauley, president of the Packard Motor Car Company. According to this view, we are nowhere near the economic limit in so far as the distribution of motor cars is concerned, but are nearing the physical limit of use of automobiles. What is meant by this is that the congestion along the main thoroughfares, particularly in the larger cities, and the restriction and lack of parking facilities take away so much from the usefulness and pleasure of the automobile, that more and more people are willing to forego the ownership of a car. There is no pleasure in driving a car on Fifth Avenue in New York City when it takes twenty minutes to travel twenty blocks. People derive no advantage from the ownership of an automobile if they want to go to a theater and can find no place to park their cars during the performance. The rapidly increasing number of accidents on the highways distinctly due to excessive crowding is also a deterrent to the ownership of motor cars.

While none of these factors can be expressed in terms of exact statistics, they undoubtedly have a bearing on the situation, and it is of interest to note what influence they have already exerted. To the engineer it is obvious that if it is necessary to carry a certain amount of a liquid, say, water, from one point to another, it can be done in two ways; either by using a large pipe and carrying the liquid at a low speed or by employing a smaller pipe and a greater velocity of flow. If the pipe happens to be a small one, the only thing to do is to use a higher velocity of flow, and substantially this is the problem in motor-car traffic. Our cities have been built for horse-drawn traffic and are entirely inadequate for ordinary motor-car traffic. Only a few of the highways are as wide as they ought to be, considering the traffic conditions of the present and the immediate future. In the past the motor car was generally looked upon as a dangerous machine, and it was believed that the only way to make it safer was to limit by law or ordinance the speed of its operation. The result was that the country was dotted with notices of maximum speeds ranging from ten miles an hour in the most backward communities to twenty and at the utmost twenty-five miles where a more enlightened view prevailed. To all practical purposes this was like trying to force a large amount of liquid through a small pipe at a slow speed, an essentially impossible task.

Of late views have begun to change. It is becoming more and more evident that it is not the speed but the care with which a motor car is operated that makes it either dangerous or safe, and that a reasonably high speed of operation is not prima facie evidence of recklessness. The result has been that more and more states have by law established higher limits of permissible speed for automobiles in intercity transportation; for example, in Indiana the limit has been raised to 35 miles, and in the wide, open spaces of Texas to as high as 60 miles. Not only this, but there is a growing conviction in many places that it is not the fast-traveling car but the excessively slow one that constitutes a menace by blocking traffic, forcing other cars to pass around it, etc. There have been no cases as yet of arrest for traveling at a speed below 25 miles per hour, but the matter is actually under serious consideration in a number of western states.

This situation is of very great interest to engineers from several points of view. In the first place, legal sanction of higher speeds will be greatly welcomed by the motor-owning community, which has felt all along that a skilled operator can safely use in open country speeds from 35 miles up—and an operator not so skilled is a menace to mankind even at far lower speeds. The adoption of higher speeds, however, will make imperatively necessary a very material improvement in automobiles—better balancing, stronger frames and axles, better springs, more reliable steering gear, larger and more effective brakes.

But what is not completely realized is that this adoption of higher speeds will mean two further things. In the first place, a car driven at an average of from 35 to 60 miles per hour, even if better built than present-day cars, will have a much shorter life. In the second place, and this is probably the most important consideration, the use of higher speeds will very unfavorably affect the present value of second-hand cars. These primarily have not been designed for higher speeds and therefore either cannot deliver them or, if they do, will go to pieces in a short time.

From this point of view the Ford situation is significant. The model T Ford car begins to rattle very noticeably at speeds below 35 miles per hour, and this may have been one of the dominant reasons why the Ford Company has finally decided to change its model. All authentic information points to the fact that the new Ford will be so planned as to be capable of smooth operation at speeds up to and probably in excess of 50 miles per hour.

The use of the higher speeds will give a greater carrying capacity to our present city streets and highways; it will create a demand for cars of new design; it will rapidly make obsolete the vast accumulation of second-hand cars which are now such a drag on the industry, and finally it will put off the day when the motor-car saturation point is to be reached to some time in the dim future.

A.S.M.E. Seattle Meeting

THE Seattle Regional Meeting of The American Society of Mechanical Engineers, held in that city on August 29 and 30, was a most successful one. Members from Vermont, Massachusetts, Connecticut, New York, Ohio and other far-distant states, many with their wives, added to the attendance from the great area of the Group VII Sections. The papers presented at the technical sessions all dealt with developments in the Far West and a running account of the discussion they occasioned will be published in the November issue of MECHANICAL ENGINEERING.

Alexander Crombie Humphreys Dies

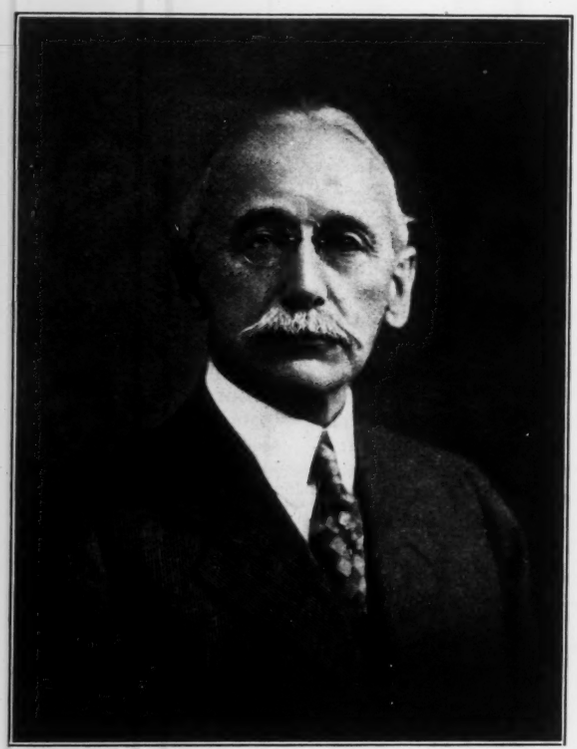
Thirty-First President of the A.S.M.E. Passes Away in Morristown, N. J., at the Age of Seventy-Six

DR. ALEXANDER CROMBIE HUMPHREYS, Past-President of The American Society of Mechanical Engineers, Chairman of the Board of Trustees and for twenty-five years President of Stevens Institute of Technology, and a water-gas engineer of international reputation, died in his seventy-sixth year at his home in Morristown, N. J., on August 14, 1927, following a general breakdown which had confined him to his bed for three weeks. His brilliant and active professional career covered a space of more than sixty years, during which his abilities in the fields of education, engineering, and administration were constantly and constructively engaged.

Dr. Humphreys was born in Edinburgh, Scotland, on March 30, 1851. He was the son of Dr. Edward R. and Margaret McNutt Humphreys. At the age of eight, Dr. Humphreys was brought to this country by his parents who settled in Boston, Mass., where the boy was educated in his father's school. So excellent was this training, and so competent the student, that at the age of fourteen he passed the preliminary test examination of the United States Naval Academy; failing of admission on account of his youth, however, he entered a Boston insurance office.

Removing to New York in 1866, Dr. Humphreys entered the employ of the New York Guaranty and Indemnity Company and was shortly made receiving teller and assistant bookkeeper, thus obtaining an experience in finance and affairs which served him in his later engineering activities.

His first contact with the gas industry, in which he was destined to lay the foundation for a world-wide reputation, came in 1872 when he became secretary-treasurer, and shortly afterward superintendent of the Bayonne & Greenville Gas Light Company. Three years of experience with the gas plant convinced Dr. Humphreys of the need of a technical education, and he made arrangements whereby he was to spend two mornings a week at Stevens Institute, studying at night and making up in the same way his absence from his usual duties. Six years was thought necessary for the completion of the course under these circumstances, but he accomplished all of the work in four and was graduated in 1881, the faculty recognizing this unusual achievement in a resolution of commendation.



ALEXANDER CROMBIE HUMPHREYS

Dr. Humphreys had married in 1872, previous to his career at Stevens, Miss Eva Guillanden, of Bergen Point, N. J. He was also, during his college years, vestryman, church treasurer, and Sunday school superintendent, a member of the Board of Education of Bayonne, N. J., and foreman of its volunteer fire department.

After graduation he became chief engineer of the Pintsch Lighting Company, for which he built many oil-gas plants, conducted experiments on a large scale, and perfected a business organization. This same genius in engineering and organization he brought to the United Gas Improvement Company of Philadelphia in 1885 as its superintendent and chief engineer. Under a uniform system of management and control devised and developed by him, many properties of this company were operated from Philadelphia.

Dr. Humphreys' first venture in the consulting engineering profession was in 1892 when, in association with Arthur G. Glasgow, he established in London the firm of Humphreys & Glasgow, designers and constructors of water-gas plants in all parts of the world, making the first successful installation of water gas in England. In his connection with the United Gas Improvement Company, Dr. Humphreys built many gas plants in North America. He remained with this company until 1894, when he formed the New York firm of Humphreys & Glasgow. Dr. Humphreys retired from the London firm in 1908, and in 1910 reorganized the New York firm as Humphreys & Miller.

In 1902 Dr. Humphreys became president of Stevens Institute of Technology at the urging of trustees, faculty, and students who recognized in him the qualities of sympathy, the ability of administration, and the knowledge of practical affairs necessary in the conduct of such an office. In the same year he succeeded Bayard Dod as president of the Board of Trustees of the Institute. In the fall of 1926 Dr. Humphreys announced his intention of retiring from the presidency of Stevens, but was persuaded to remain until June of this year to round out twenty-five years of service. At the time of his death he was chairman of the Board of Trustees of the Institute.

Dr. Humphreys brought to the educational world the experience of a man of affairs and of an eminent consulting engineer who had won his technical education at the cost of personal sacrifice, and his sane views on educational matters are embodied in the presidential address which he delivered before The American Society of Mechanical Engineers at its Annual Meeting in 1912.

The University of Pennsylvania recognized Dr. Humphreys' achievements by conferring on him the degree of Sc.D., and Columbia University, Princeton University, and New York University honored him with the degree of LL.D.

Dr. Humphreys was a member of many professional societies. He joined The American Society of Mechanical Engineers in 1884, served as Manager from 1907 to 1910, as Vice-President from 1910 to 1911, and was President in 1912. He was an active member of many of the Society's committees. From 1912 to 1916 he was a trustee of the United Engineering Societies. He was also past-president of the American Gas Light Association, the American Gas Institute, the Engineers' Club of New York, and the American Institute of Consulting Engineers, and a trustee of the Carnegie Foundation for the Advancement of Teaching. He belonged to many other societies and clubs.

As a patron of American artists, Dr. Humphreys made a valuable collection of 150 paintings, which he sold in 1917, and through his business connections in England he was able to attract the attention of European cities and collectors to the work of American artists.

Dr. Humphreys is survived by his widow and one daughter, Mrs. A. D. Turnbull, of Morristown. His two sons were drowned in the Nile in 1902, when the older made an unsuccessful attempt at saving the younger.

The following letters of appreciation from fellow-members and acquaintances of long standing have been received.

In the death of Dr. Alexander C. Humphreys the engineering profession and the community lose an outstanding figure, and I lose a dear and valued friend.

Because I have known him well for many years I can the better testify to the inherent fineness of his nature and the nobility of his character.

In the best and highest sense, Dr. Humphreys was the true gentleman, richly deserving the honor and regard which he won in every relation of his useful life.

WORCESTER R. WARNER.

My remembrances of Dr. Humphreys are always to me a pleasure. He was a man of dignified and gracious manner; his voice was resonant with good cheer; his conversation, while often very merry, was always sound and true; in fact, his love of truth and honesty of purpose gave quality to all his undertakings.

He was a tireless worker. The enterprises that he chose to support were many and varied; and where he worked, there were his sympathies. Work with him was the application of a spirit of devotion; it was the core of the life that he enjoyed living. For years he was the dominant figure in the influences that centered in Stevens Institute. He was the guide and inspiration of the youth in his care, and they treasure his memory; and there is no part of man's achievement of greater worth than the record which lies in the loving remembrance of those with whom he has lived and worked.

These are some of the lines in my picture of Dr. Humphreys which at once become prominent when I think of him.

W. F. M. GOSS.

Dr. Alexander C. Humphreys was kindly and sympathetic. At the same time he was aggressive in advocating and sustaining high ideals in the engineering profession, and in an endeavor to keep the affairs and traditions of the Society on a high level. His interest was unfailing. He never hesitated to speak out when he thought it was for the good to do so. His influence was good, and the results of his unceasing interest will be permanent.

CHARLES T. MAIN.

Only those privileged to know Dr. Humphreys intimately can appreciate how great is his loss. His place in the engineering profession is too well known to be told again. One marvels at the variety and extent of his attainments; his professional and business relations; his membership in societies at home and abroad; his courage and determination. Starting to work at 14, he was 30 years old when he was graduated from Stevens. That is a chapter in a man's life rarely met. And how magnificent were succeeding chapters to the very end.

On the personal side one must not forget that Dr. Humphreys was born a Scot. He loved his friends, and if he did not hate his enemies, they were for him outside the pale. He crossed swords promptly in debate, and was vigorous in attack and defense. There was no compromise. In particular was he zealous in defense of the honor and integrity of himself and friends. A valiant champion of causes he espoused, a fearless opponent of those he denied.

Rugged, upright, tall, and widespreading, was his tree of life. A precious memory.

MORTIMER E. COOLEY.

The outstanding characteristic of Dr. Humphreys was, it seemed to me, his thorough competence.

I came in contact with him only through our contemporaneous service in the Council and in the United Engineering Society, and he always impressed me with the fact that here was a quiet, courteous, and thoroughly competent gentleman.

FRED J. MILLER.

A.S.M.E. Iron and Steel Professional Division To Be Organized

COMPLYING with the request of a large number of its members who are prominent in the mechanical-engineering activities of the iron and steel industries, the Council of The American Society of Mechanical Engineers has recently sanctioned the organization of the Iron and Steel Professional Division more fully to serve their special technical needs.

The mechanical problems of the iron and steel industry are closely related to those of mechanical engineering in general, and the new Division as organized will be effective in promoting a useful exchange of ideas and in throwing light on many problems arising from the special conditions obtaining in this industry.

The following analysis of engineering problems of the iron and steel industry was made by Roy C. Brett, organizing chairman of the new Division and also chairman of the Cleveland Section of the Society, which sponsored the formation of the Division. This analysis was for the purpose of outlining the scope of usefulness and value of the new Division to the profession and industry.

SCOPE OF IRON AND STEEL DIVISION OF THE A.S.M.E.

Broadly, the iron and steel industry is concerned with three distinct types of mechanical problems, namely, those of

1 Blast Furnaces or Pig-Iron Manufacturing
2 Open-Hearth Furnaces (and Bessemer Converters) or Steel Making
3 Rolling Mills, or the Art of Rolling Steel.

Blast Furnaces. In connection with the manufacture of pig iron at blast furnaces there are three important operations: (1) handling of materials, (2) smelting of ores, and (3) development of power from waste heat.

Such problems as are connected with the handling of materials have heretofore been discussed by the Materials Handling Division of the Society, but the problems are so unique and in general so localized with the industry that it is quite proper that these problems be discussed by the proposed new Division in coöperation with the Materials Handling Division.

In addition to the problems of handling materials the blast-furnace engineer is interested in the creation of the blast, which means equipment such as blowers, piping, pressure control, the heating of the blast, and in some cases drying it. Equipment of very large size is involved, and the matter of reliability is of paramount importance.

The blast furnace of today is as much a gas-making plant as it is a plant for making pig iron. Blast-furnace gases are either burned under boilers or consumed in gas engines of huge size chiefly used to drive the blowers, but at times to generate electric power. All of these are again problems for the mechanical engineer.

Practically all large blast-furnace plants operate their own coke ovens. This involves in addition to the handling of materials, high-temperature carbonization, and the problem of utilizing the various by-products as well as the coke-oven gas. All of these problems are of great interest to mechanical engineers in view of the present effort toward the developing of commercial methods of low-temperature carbonization of coal. The various machines for handling the materials charged into the blast furnace—cranes, mixers, pig-casting machines, etc.—all present problems in mechanical design, where apparently there is room for considerable improvement.

Open-Hearth Plant. While the metallurgical side of melting and conditioning the metal are of course, outside the scope of the proposed Division, many problems legitimately within the purview of the mechanical engineer are involved. The coal used in the open hearth is pretreated in gas producers, apparatus on which the Society has had many papers; from the producers it passes through the regenerating checkerwork, and the brick used in this has to stand conditions also encountered in power-plant operation.

Substantially the same problems are met with in maintaining the roof of the open hearth as in the roofs and arches of modern boiler furnaces, and the coöperation of the two groups of engineers may bring about useful improvements. The great problem of heat recovery in open-hearth-furnace operation which is attracting increased attention is a purely mechanical one. The handling of ingots after casting, such as stripping, chipping, etc. means the use of hydraulic and compressed-air equipment.

Rolling Mills. For the most part the rolling-mill operation is one involving mechanical considerations primarily, the metallurgical features being largely secondary and controlled by mechanisms. Here the mechanical engineer should be in control. The design of the mill involves mechanical considerations of stresses, drives, bearings, lubrication, etc. Among the problems now of particular interest to rolling-mill engineers, the following are of a strictly mechanical character: Use of anti-friction bearings. These have been successfully introduced in rolling-mill motors, beds, and cranes. Of late there has been a tendency to introduce them also in the smaller mills such as continuous sheet rolling mills. The large mills such as bloomers, roughers, etc. use plain bearings, but more and more effort is being made to increase their efficiency of operation and reduce power consumption.

Attempts have been recently made both here and abroad to true the rolls while hot so as to eliminate the necessity for bellying them. This is in line with what mechanical engineers have been interested in lately, namely, the cutting of metals and their behavior at high temperatures.

The question of mill drive through gears, reducers, etc. is of course a purely mechanical one. The lubrication of rolling mills belongs to the same class.

Steel Works Accessories. Steel works require accessory services which are comparatively inconspicuous from the outside, but are nevertheless often of surprisingly large size. Every steel mill has a huge power plant. The amount of water handled by a mill of even medium size is surprisingly large. As a rule a mill operates numerous compressed-air tools. Hydraulic machinery is used quite extensively, in addition to which the various tables, cooling beds, manipulators, shears, etc. involve a large number of drives, operated sometimes individually but more often recently by electric motors.

While, therefore, there are certain features of steel-mill operation which are entirely outside the scope of the new Division, such as processes of a purely metallurgical character, it may be conservatively stated that by far the largest work of a steel mill is not metallurgical but mechanical.

A.S.M.E. Division Meetings in October

First National Fuels Meeting
St. Louis, Mo., October 10–13

Second National Wood Industries Meeting
Grand Rapids, Mich., October 17–18

First National Management Meeting
Rochester, N. Y., October 26–27